SR 520 WEST APPROACH BRIDGE NORTH

Underwater Sound Level Report: Permanent Bridge Replacement

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

September, 2015

TABLE OF CONTENTS

List of Tables

List of Figures

ACRONYMS AND ABBREVIATIONS

dB	decibel
Hz	hertz
µPa	micro-Pascal
NIST	National Institute of Standards and Technology
Pa	Pascal
RMS	route 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 24-inch steel battered and 30-inch steel plumb piles for the Washington State Department of Transportation (WSDOT) State Route (SR) 520 West Approach Bridge North Project between November 2014 and April 2015. Data was collected for thirty-eight 30-inch piles and two 24-inch battered piles. Twenty of the piles monitored were located on the West side of Foster Island and the other twenty were located on the east side of Foster Island. Confined bubble curtains were deployed for all piles impact driven in water depths greater than two feet to attenuate potential underwater noise effects. All measurements were collected 10 meters from the pile. 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.

On the west side of Foster Island, data for the first two piles were not able to be saved and post processed due to an incompatibility issue with the sound recording software and Windows 7. However, real-time field notes were able to determine the peak and estimate the cumulative Sound Exposure Level (cSEL) for each pile.

For piles west of Foster Island Table 1 shows that 11 of the 20 monitored piles exceeded the peak threshold of 169 dB_{peak}. While this threshold applied when the pile driving monitoring began, it was changed to 188 dB_{peak} during the ESA consultation which was in progress during monitoring. 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 24-in & 30-in Piles Attenuated Underwater Sound Levels-West of Foster Is.

Pile #	Date	Pile Size (inches)	Peak Threshold (dB)	Peak at 10 meters (dB)	Exceedence?	RMS (dB)	Single Strike SEL (dB)	Cumulative SEL (dB)
1	11/13/14	24	169	180	Y	-	-	*
2***	11/13/14	24	169	170	Y	-	-	*
3	11/17/14	30	169	174	Y	168	156	177
4	11/17/14	30	169	176	Y	168	157	178
5	11/17/14	30	169	178	Y	169	159	180
6***	11/18/14	24	169	180	Y	164	154	166
7	11/19/14	30	169	172	Y	167	159	171
8	11/19/14	30	169	182	Y	166	156	177

Pile #	Date	Pile Size (inches)	Peak Threshold (dB)	Peak at 10 meters (dB)	Exceedence?	RMS (dB)	Single Strike SEL (dB)	Cumulative SEL (dB)
9	11/19/14	30	169	168	N	160	150	170
10***	11/20/14	30	169	166	N	160	148	172**
11	12/15/14	30	169	163	N	145	137	168**
12	12/16/14	30	169	161	N	151	143	165**
13	12/16/14	30	169	161	N	150	143	169**
14	12/16/14	30	169	165	N	151	142	169**
15	12/19/14	30	169	162	N	151	143	166**
16	12/19/14	30	169	167	N	164	156	175**
17	02/04/15	30	169	170	Y	162	154	166**
18	02/04/15	30	169	170	Y	161	152	159**
19	02/05/15	30	169	169	N	151	144	169**
20	02/05/15	30	169	177	Y	155	147	174**

* Data not saved due to software malfunction
** Cumulative SEL calculated using the total number of strikes
*** Battered Pile
**** The 169 dB_{peak} threshold was applied when monitoring began, but it was later changed to 188 dB_{peak} during an ESA consultation that was in progress during the monitoring (based on the results of the WCB and WABN monitoring).

For piles east of Foster Island Table 2 shows that 3 out of the first 7 monitored piles exceeded the peak threshold of 169 dB_{peak} and 5 out of the remaining 13 monitored piles exceeded the peak threshold of 178 dB. The peak attenuated sound levels measured ranged between 158 dB peak and 200 dB_{peak}. Results of monitoring the impact pile driving operation are shown in Table 1.

Table 2: Summary of 30-in Piles Attenuated Underwater Sound Levels-East of Foster Is.

Pile #	Date	Peak Threshold* (dB)	Peak at 10 meters (dB)	Exceedence?	RMS (dB)	Single Strike SEL (dB)	Cumulative SEL (dB)
1	01/28/15	169	191	Y	172	156	175
2	01/28/15	169	167	N	165	157	182**
3	01/28/15	169	158	N	155	147	170**
4	01/31/15	169	169	Y	157	149	160**
5	01/31/15	169	168	N	153	161	180**
6	01/31/15	169	170	Y	164	156	178**
7	01/31/15	178	166	N	162	154	171**
8	01/31/15	178	168	N	160	150	162
9	02/03/15	178	165	N	160	147	165

Pile #	Date	Peak Threshold* (dB)	Peak at 10 meters (dB)	Exceedence?	RMS (dB)	Single Strike SEL (dB)	Cumulative SEL (dB)
10	02/03/15	178	166	N	151	143	158
11	03/27/15	178	169	N	166	158	178**
12	03/27/15	178	169	N	166	158	176**
13	03/27/15	178	162	N	160	157	179**
14	03/28/15	178	171	N	170	162	183**
15	03/28/15	178	169	N	167	159	176**
17	4/11/2015	178	193	Y	177	165	186
18	4/12/2015	178	200	Y	187	171	191
19	4/12/2015	178	196	Y	179	167	188
20	4/12/2015	178	198	Y	178	168	189
21	4/12/2015	178	194	Y	176	165	185

* The 169 dB_{peak} threshold was applied when monitoring began, but it was later changed to 188 dB_{peak} during an ESA consultation that was in progress during the monitoring (based on the results of the WCB and WABN monitoring).
** Cumulative SEL calculated using the total number of strikes

INTRODUCTION

The Washington State Department of Transportation (WSDOT) constructed temporary work trestles adjacent to the SR 520 Bridge (Figure 1). The trestles are necessary to provide a platform from which the construction workers can build the new bridge to the north of the existing SR 520 Bridge without interfering with traffic on the existing SR 520. This platform is also for drilled shafts that will be constructed adjacent to existing SR 520 bridge columns. The drilled shafts will be constructed deeper than the existing bridge columns, which will expose the existing bridge to risk of settlement if undermining occurs. Oscillators provide a means of torsionally installing deep casings for stability in certain soil conditions or where debris is anticipated that could hamper installation by conventional means (i.e., vibratory pile driving). Oscillators will likely be needed to install these casings near the existing bridge in order to mitigate the risk of damage to the existing in-service bridge. Because oscillators produce more torque and reaction forces than can safely be resisted by a barge or other floating work platform, a highly stable work platform would be required. Additionally, shaft casing templates may require sufficient stability to offset torsional reaction forces.

Figure 1: SR 520 West Approach Bridge North Project work trestle

PROJECT AREA

The project is located on the west end of SR 520 between east and the west side of Foster Island and Union Bay. Figure 1 indicates the location of the proposed work trestle. The work trestle project will impact up to 100 30-inch steel piles to bearing capacity to support the work trestle. There were up to 100 piles proofed with an impact hammer for the work trestle.

Although there is an estimated total of 778 piles needed for the work trestle, not all of the piles will require proofing with an impact hammer. All piles were driven with a vibratory hammer initially, but the plumb piles would need to be proofed to ensure that sufficient bearing capacity has been reached. Each work trestle is oriented so that the shaft or shafts can be reached by the drilling equipment and also in such a way that barges and skiffs carrying workers, equipment, and supplies can also access the platform.

For the West Approach Bridge North, underwater and airborne noise monitoring was performed in Union Bay west of Foster island and east of Foster Island.

PILE INSTALLATION LOCATION

A minimum of ten steel piling installed during the initial pile driving activity west of Foster Island, five steel piling installed at the mid-point of the piling installation , and five steel piling installed at the end point and near completion of the piling installation (20 piles in total)were monitored. For east of Foster Island, ten steel piles installed initially, five at the mid-point of the piling installation and five at the end point or completion of pile installation , for a total of 20 piles, east of Foster Island.

The hydrophone is located at 10 meters for most of the piles except for few piles where it was not safe to monitor within that proximity. Therefore, the hydrophone was located 11 meters away from pile 8 and 12 meters away from pile 9 for piles monitored west of Foster Island. East of Foster Island pile 11 was monitored 13 meters away. Monitoring at a range of 3H, where H is the water depth of the pile, was not necessary because the distance 3H was approximately 10 meters or less.

Hydroacoustic monitoring of steel pile driving included:

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

Table 3 lists the structure installed, the water depth, and the number and size of piles that were installed.

Table 3. 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*	*778 24-30-inch hollow steel piles*

Figures 2 thru 6 indicate 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 trestle west of Foster Island

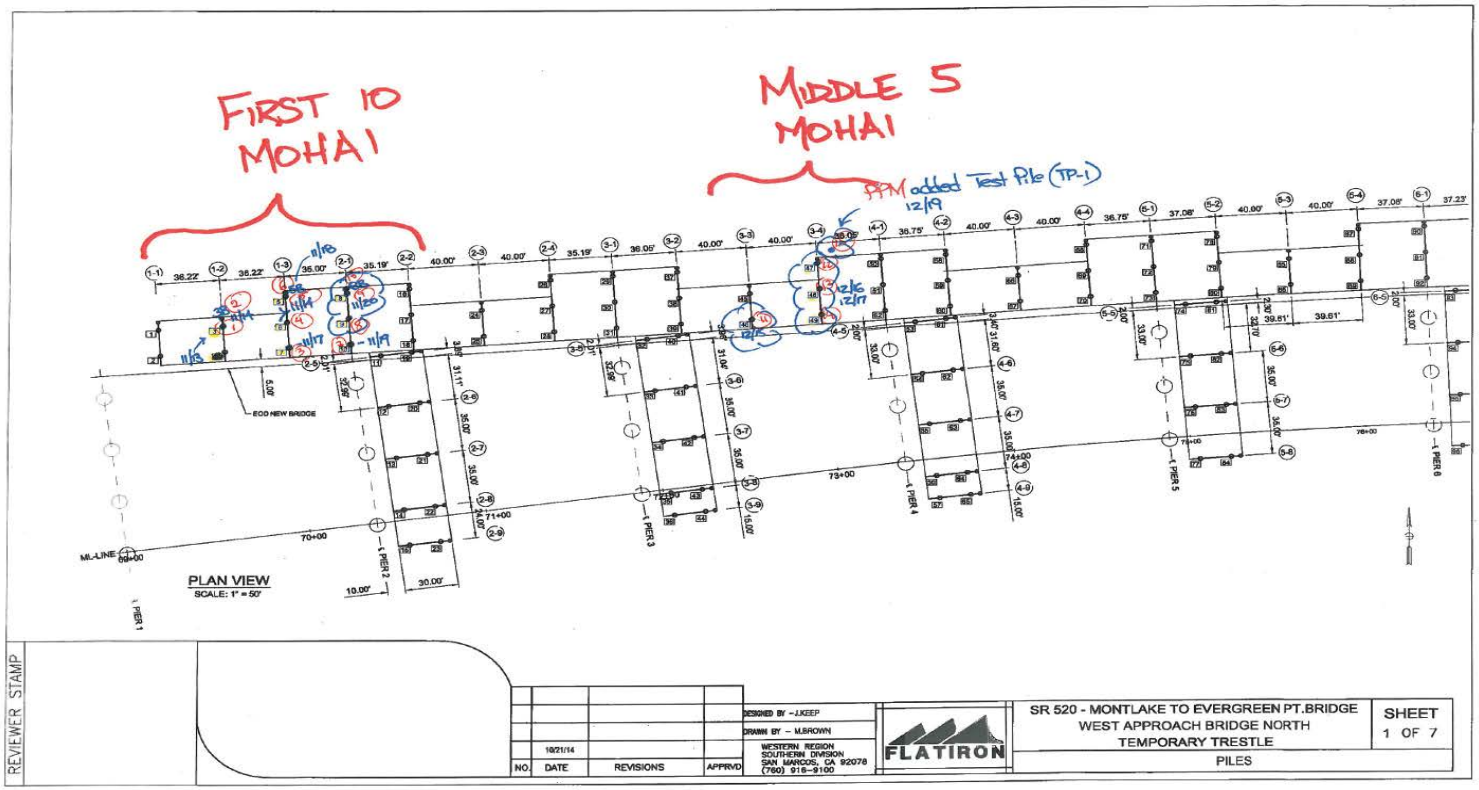


Figure 3: The work trestle west of Foster Island

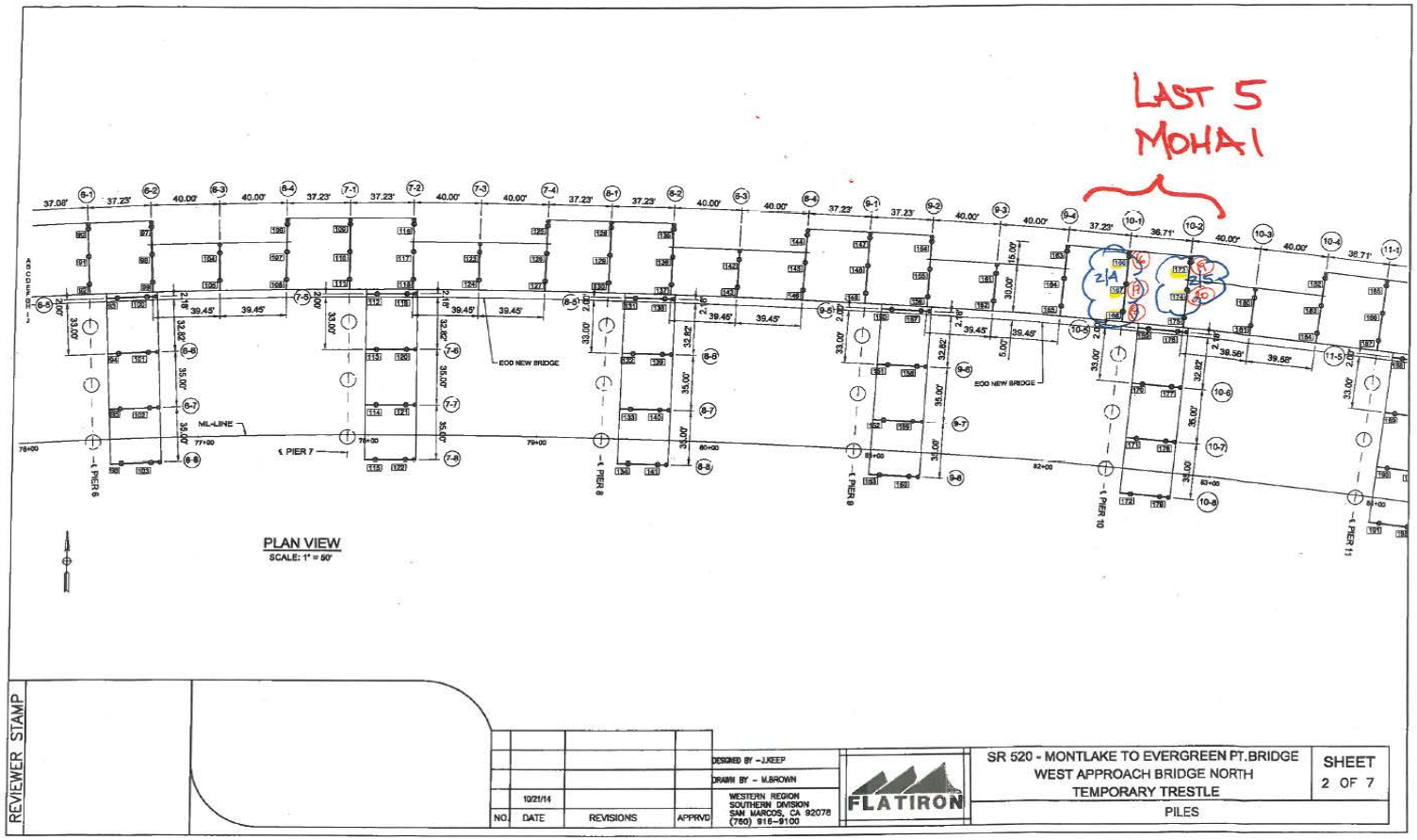


Figure 4 : The work trestle east of Foster Island

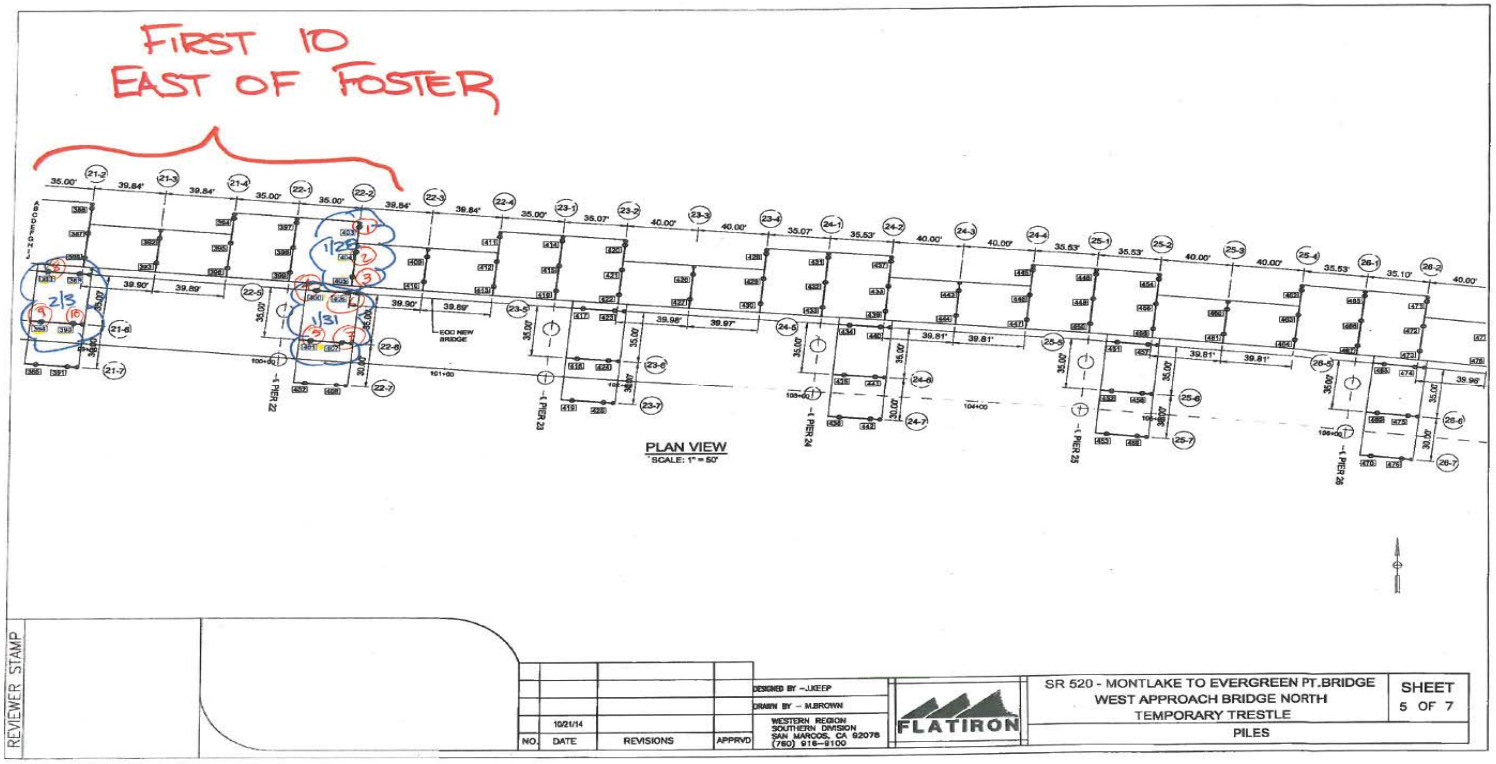


Figure 5 : The work trestle east of Foster Island

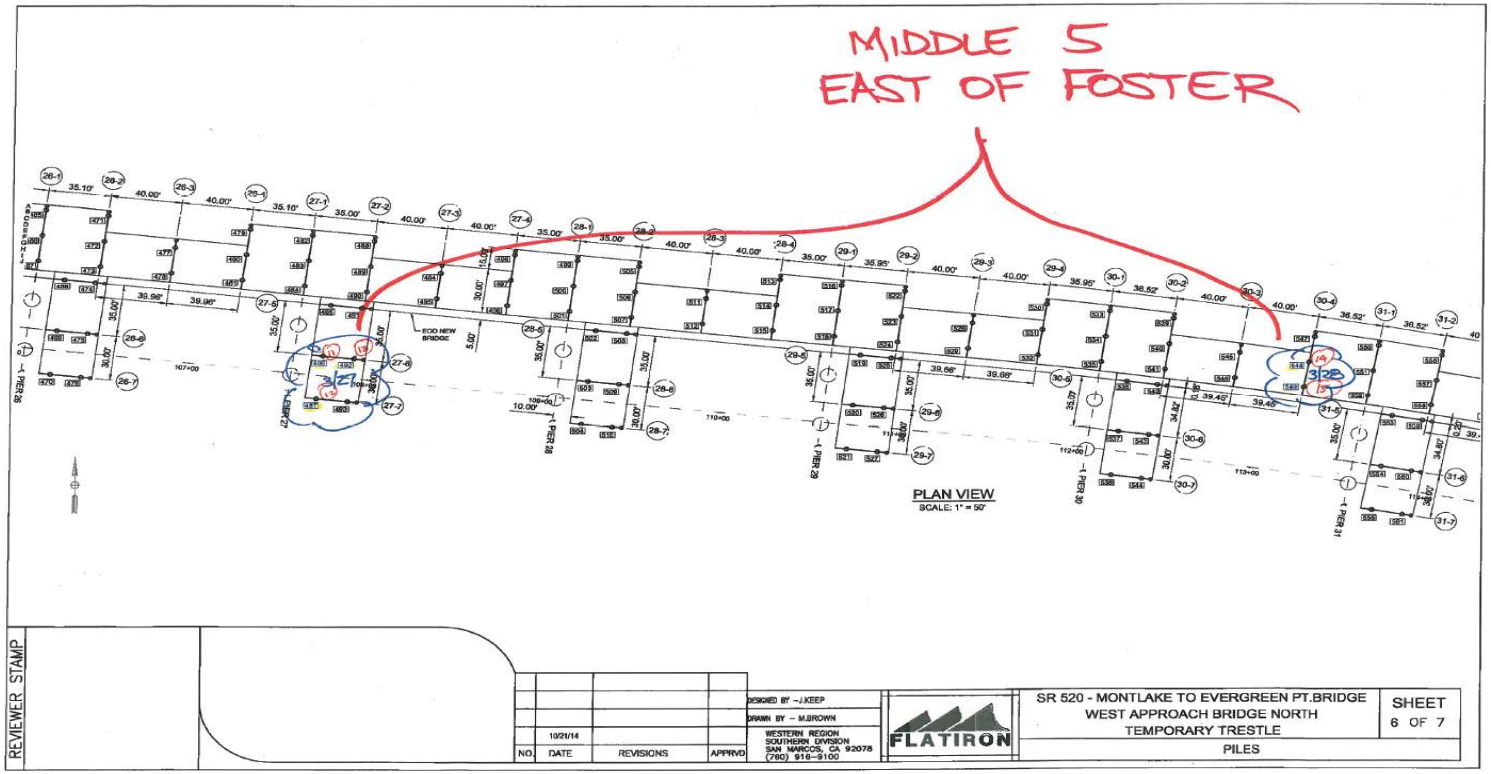
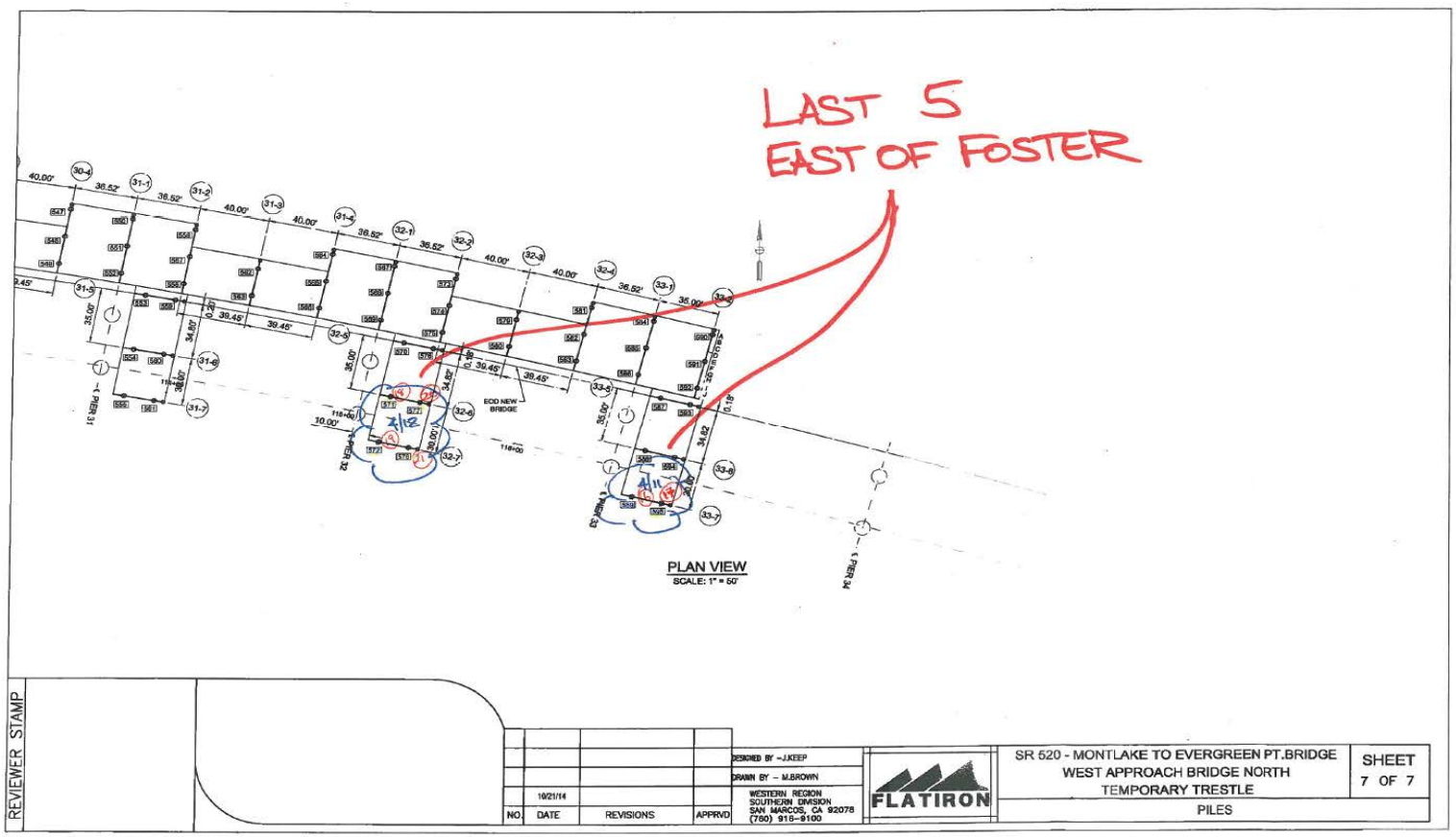


Figure 6 : The work trestle east of Foster Island



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 Pascal (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 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.

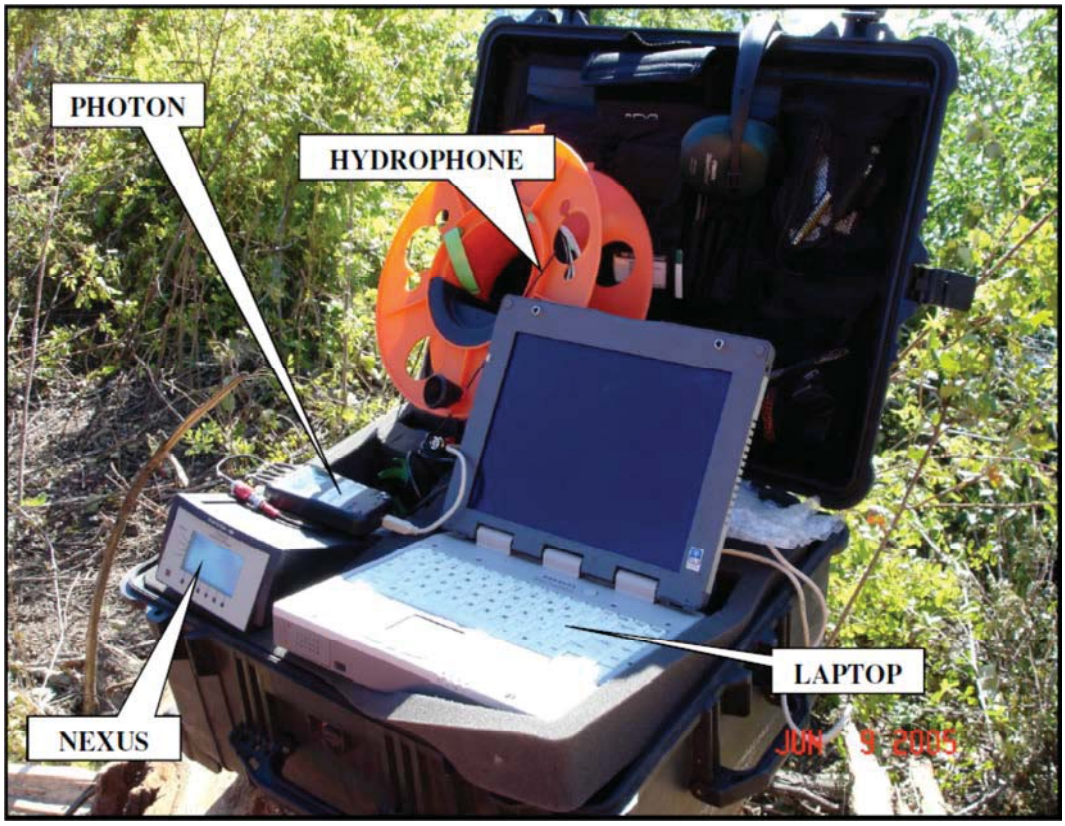
METHODOLOGY

Typical Equipment Deployment

The hydrophone was deployed from the contractors raft near the piles or from the shoreline, or work trestle. 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 7: Near Field Acoustical Monitoring Equipment



Forty steel piles, initially vibratory driven were monitored with the sound attenuation bubble curtain system active when proofed with impact hammer.

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 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 piles west of Foster Island*
- 169 dB_{peak} at 32.8 feet (10 meters)

For piles east of Foster Island*
- 169 dB_{peak} at 32.8 feet (10 meters) from Pier 17 to Pier 29
- 178 dB_{peak} at 32.8 feet (10 meters) at Pier 29
- 178 dB_{peak} at 32.8 feet (10 meters) from Pier 29 to the eastern project limit

*The 169 dB_{peak} and 178 dB_{peak} thresholds were applied when monitoring began, but it was changed to 188 dB_{peak} during an ESA consultation that was in progress during the monitoring (based on the results of the WCB and WABN monitoring).

RESULTS

Underwater Sound Levels

WSDOT monitored a total of forty 24inch & 30-inch steel piles for underwater noise. West of Foster Island, data for the first two piles were not able to be saved and post processed due to an incompatibility issue with the sound recording software and Windows 7. Real-time field notes of the peak values are documented in the field are provided for the piles not recorded. All other piles are analyzed in the paragraphs below and summarized in Table 4.

West of Foster Island

Pile 1

Pile 1 is located near the shore, east of Pier 1 and south of Pile 2. The pile had an absolute attenuated peak value of 180 dB_{peak} at 10 meters. This pile has exceeded the 169 dB_{peak} threshold. This may be due to the muck layer was thinner and was not providing additional noise attenuation. The attenuated $RMS_{90\%}$ was not calculated for this pile. Due to a software malfunction, the data was lost without being recorded. The distance to the 169 dB_{peak} threshold using the practical spreading model from the pile location is 176 feet. The cSEL at 10 meters estimated by subtracting 20 dB from the absolute peak level and adding this number to the product of the Log of the total number of strikes multiplied by 10 is 185 dB_{cSEL}.

Pile 2

Pile 2 is a battered pile (driven at an angle) located next to Pile 1, near the shore and east of Pier 1. The pile had an absolute attenuated peak value of 170 dB_{peak} at 10 meters. This pile has exceeded the 169 dB_{peak} threshold for this section of the project. The attenuated $RMS_{90\%}$ was not calculated for this pile. Due to a software malfunction, the data was lost without being recorded. The distance to the 169 dB_{peak} threshold using the practical spreading model from the pile location is 38 feet. The cSEL at 10 meters estimated by subtracting 20 dB from the absolute peak level and adding this number to the product of the Log of the total number of strikes multiplied by 10 is 161 dB_{cSEL}.

Pile 3

Pile 3 is a located southeast of Pile 1 and south of Pile 4, between Piers 1 and 2. The pile had an absolute attenuated peak value of 174 dB_{peak} at 10 meters. This pile has exceeded the 169 dB_{peak} threshold for this section of the project. The attenuated $RMS_{90\%}$ at 10 meters is 168 $dB_{RMS.}$ The distance to the 169 dB_{peak} threshold using the practical spreading model from the pile location is 71 feet. The cSEL calculated based on each measured pile strike at 10 meters is 177 dB_{cSEL}.

Pile 4

Pile 4 is a located east of Pile 1 and north of Pile 3, between Piers 1 and 2. The pile had an absolute attenuated peak value of 176 dB_{peak} at 10 meters. This pile has exceeded the 169 dB_{peak} threshold for this section of the project. The attenuated $RMS_{90\%}$ at 10 meters is 168 $dB_{RMS.}$ The distance to the 169 dB_{peak} threshold using the practical spreading model from the pile location is 98 feet. The cSEL calculated based on each measured pile strike at 10 meters is 178 dB_{cSEL}.

Pile 5

Pile 5 is located north of Pile 4 between Piers 1 and 2. This pile had an absolute attenuated peak value of 178 dB_{peak} at 10 meters. This pile exceeded the 169 dB_{peak} threshold for this section of the project. The attenuated $RMS_{90\%}$ at 10 meters is 169 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 131 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 180 $dB_{cSEL.}$

Pile 6

Pile 6 is a battered pile located next to Pile 4. This pile had an absolute attenuated peak value of 180 dB_{peak} at 10 meters. This pile exceeded the 169 dB_{peak} threshold for this section of the project. The attenuated $RMS_{90\%}$ at 10 meters is 164 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 178 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 166 $dB_{cSEL.}$

Pile 7

Pile 7 is located east of Pile 3, immediately next to Pier 2 and south of Pile 8. This pile had an absolute attenuated peak value of 172 dB_{peak} at 11 meters. This pile exceeded the 169 dB_{peak} threshold at 10 meters for this section of the project. The attenuated $RMS_{90\%}$ at 11 meters is 167 $dB_{RMS.}$ The distance to the 169 dB_{peak} threshold using the practical spreading model is 57 feet from the pile location. The cSEL calculated based on each measured pile strike at 11 meters is 171 dB_{cEL}.

Pile 8

Pile 8 is located east of Pile 4, immediately next to Pier 2 and south of Pile 9. This pile had an absolute attenuated peak value of 181 dB_{peak} at 11 meters. This pile exceeded the 169 dB_{peak} threshold for section of the project. The attenuated $RMS_{90\%}$ at 11 meters is 166 $dB_{RMS.}$ The distance to the 169 dB_{peak} threshold using the practical spreading model is 228 feet from the pile location. The cSEL calculated based on each measured pile strike at 11 meters is 177 dB_{cSEL}.

Pile 9

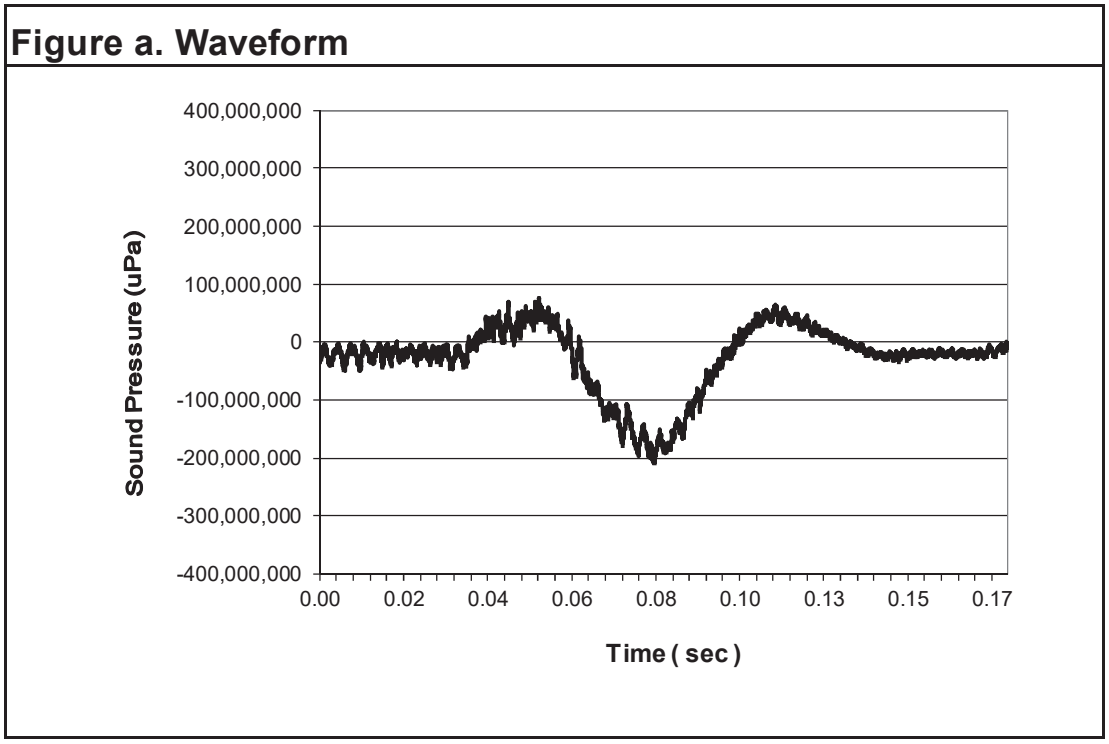
Pile 9 is located east of Pile 5, immediately next to the Pier 2 and adjacent to Pile 10. This pile had an absolute attenuated peak value of 167 dB_{peak} at 12 meters. This is below the 169 dB_{peak} threshold calculated at 10 meters. The attenuated $RMS_{90\%}$ at 12 meters is 160 $dB_{RMS.}$ The distance to the 169 dB_{peak} threshold using the practical spreading model is 29 feet from the pile location. The cSEL calculated based on each measured pile strike at 12 meters is 170 dB_{cSEL}.

Pile 10

Pile 10 is a battered pile located east of Pile 6 near Pier 2. This pile had an absolute attenuated peak value of 166 dB_{peak} at 10 meters. This is below the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 160 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 21 feet from the pile location. The cSEL at 10 meters is calculated by adding 10 times the LOG of the total number of strikes to the single strike SEL was 177 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike SEL

for each pile strike. The majority of the piles on west of Foster Island had seismic waves that were more subtle for pile strikes similar to the one shown in Figure 8.

Figure 8: An example Waveform of Piles on West of Foster Island



Pile 11

Pile 11 is located east of Pier 3. This pile had an absolute attenuated peak value of 163 dB_{peak} at 10 meters. This is below the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 145 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 13 feet from the pile location. The cSEL at 10 meters is calculated by adding 10 times the LOG of the total number of strikes to the single strike SEL is 165 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 12

Pile 12 is located between Piers 3 and 4 and north of Pile 13. This pile had an absolute attenuated peak value of 161 dB_{peak} at 10 meters. This is below the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 151 dB_{RMS} and. The distance to the 169 dB_{peak} threshold using the practical spreading model is 10 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 165 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 13

Pile 13 is located between Piers 3 and 4 and south of Pile 12. This pile had an absolute attenuated peak value of 161 dB_{peak} at 10 meters. This is below the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 150 dB_{RMS} and. The distance to the 169 dB_{peak} threshold using the practical spreading model is 10 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 169 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile14

Pile 14 is located between Piers 3 and 4 and south of Pile 13. This pile had an absolute attenuated peak value of 165 dB_{peak} at 10 meters. This is below the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 151 dB_{RMS} and. The distance to the 169 dB_{peak} threshold using the practical spreading model is 18 feet from the pile location. The cSEL at 10 meters is calculated by adding 10 times the LOG of the total number of strikes to the single strike SEL is 170 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 15

Pile 15 is located west of Pier 4 and north of Pile 14. This pile had an absolute attenuated peak value of 162 dB_{peak} at 10 meters. This is below the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 151 dB_{RMS} and. The distance to the 169 dB_{peak} threshold using the practical spreading model is 11 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 165 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 16

Pile 16 is located along Pier 10 and north of Pile 17. This pile had an absolute attenuated peak value of 167 dB_{peak} at 10 meters. This is below the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 164 dB_{RMS} and. The distance to the 169 dB_{peak} threshold using the practical spreading model is 24 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 177 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 17

Pile 17 is located along Pier 10 and north of Pile 18. This pile had an absolute attenuated peak value of 170 dB_{peak} at 10 meters. This exceeded the 169 dB_{peak} threshold for this section of the project. The attenuated $RMS_{90\%}$ at 10 meters is 162 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 38 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 177 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 18

Pile 18 is located along Pier 10 and south of Pile 17. This pile had an absolute attenuated peak value of 170 dB_{peak} at 10 meters. This exceeded the 169 dB_{peak} threshold for this section of the

project. The attenuated $RMS_{90\%}$ at 10 meters is 161 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 38 feet from the 10 meter location. The cSEL calculated based on each measured pile strike at 10 meters is 174 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 19

Pile 19 is located east of Pier 10 and east of Pile 16. This pile had an absolute attenuated peak value of 169 dB_{peak} at 10 meters. This is at but not exceeding the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 151 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 33 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 166 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 20

Pile 20 is located east of Pier 10 and east of Pile 17. This pile had an absolute attenuated peak value of 177 dB_{peak} at 10 meters. This exceeded the 169 dB_{peak} threshold for this section of the project. The attenuated $RMS_{90\%}$ at 10 meters is 155 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 112 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 168 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Table 4: Summary of Underwater Broadband Sound Levels for the SR 520 WABN Project West of Foster Island[3]

Pier #	Pile #	Date & Time	Pile Diameter (inches)	Hydrophone Range (m)	Hydrophone Depth (feet)	Total Number Of Strikes	Highest Absolute Peak[3] (dB)	$RMS_{90\%}$ (dB_j)	Single Strike $SEL_{90\%}$ (dB)	Avg. Peak ± s.d. (Pascal)	Avg. RMS ± s.d. (Pascal)	Cumulative SEL (dB)
Between 1 & 2	1[1]	11/13/14 10:00 AM	24	10	-	325	180	n/a	160	n/a	n/a	185[4]
	2[1,2]	11/14/14 2:38 PM	24	10	-	12	170	n/a	150	n/a	n/a	161[4]
Between 1 & 2	3	11/17/14 2:12 PM	30	10	6	513	174	168	156	372±105	187±49	177
	4	11/17/14 2:28 PM	30	10	6.5	191	176	168	157	466±105	230±49	178
	5	11/17/14 2:55 PM	30	10	6.5	232	178	169	159	652±120	370±77	180
	6[2]	11/18/14 5:53 PM	24	10	7	26	180	164	154	408±143	110±49	166
	7	11/19/14 2:02 PM 2:10 PM	30	11	7	280	172	167	159	210±28	101±28	171
	8	11/20/14 2:20 PM	30	11	6	764	181	166	156	466±32	230±49	177
	9	11/20/14 2:41 PM	30	12	6	866	167	160	150	157±32	91±20	170
	10[2]	11/20/14 3:31 PM	30	10	6	277	166	160	148	n/a	n/a	177[4]
Between 1 & 2	11	12/15/14 1:12 PM	30	10	7	613	163	145	137	n/a	n/a	165[4]
	12	12/16/14 3:37 PM 12/17/14 9:27 AM	30	10	6	224	161	151	143	n/a	n/a	165[4]
	13	12/16/14 3:55 PM 12/17/14 9:13 AM	30	10	6	437	161	150	143	n/a	n/a	169[4]
	14	12/16/14 2:14 PM 12/17/14 8:55 AM	30	10	6	574	165	151	142	n/a	n/a	170[4]

Pier #	Pile #	Date & Time	Pile Diameter (inches)	Hydrophone Range (m)	Hydrophone Depth (feet)	Total Number Of Strikes	Highest Absolute Peak[3] (dB)	$RMS_{90\%}$ ($dB_)$	Single Strike $SEL_{90\%}$ (dB)	Avg. Peak ± s.d. (Pascal)	Avg. RMS ± s.d. (Pascal)	Cumulative SEL (dB)
	15	12/19/14 11:28 AM 12/19/14 11:32 AM	30	10	6	160	162	151	143	n/a	n/a	165[4]
10	16	02/04/15 11:10 AM	30	10	4.5	125	167	164	156	n/a	n/a	177[4]
	17	02/04/15 11:21 AM	30	10	4.5	192	170	162	154	n/a	n/a	177[4]
	18	02/04/15 11:30 AM	30	10	4.5	155	170	161	152	n/a	n/a	174[4]
	19	02/05/15 1:10 PM	30	10	4.5	173	169	151	144	n/a	n/a	166[4]
	20	02/05/15 1:21 PM	30	10	6	124	177	155	147	n/a	n/a	168[4]

[1] Data not saved due to software malfunction

[2] Battered Piles

[3] The 169 dB_{peak} threshold was applied when monitoring began, but it was changed to 188 dB_{peak} during an ESA consultation that was in progress during the monitoring (based on the results of the WCB and WABN monitoring).

[4] Cumulative SEL calculated using the total number of strikes

East of Foster Island

Pile 1

Pile 1 is located east of Pier 22 and north of Pile 2. This pile had an absolute attenuated peak value of 191 dB_{peak} at the 10 meter. This pile exceeded the 169 dB_{peak} threshold for this section of the project. The attenuated $RMS_{90\%}$ is 172 dB_{RMS} at 10 meters. The distance to the 169 dB_{peak} threshold using the practical spreading model is 67 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 175 dB_{cSEL}.

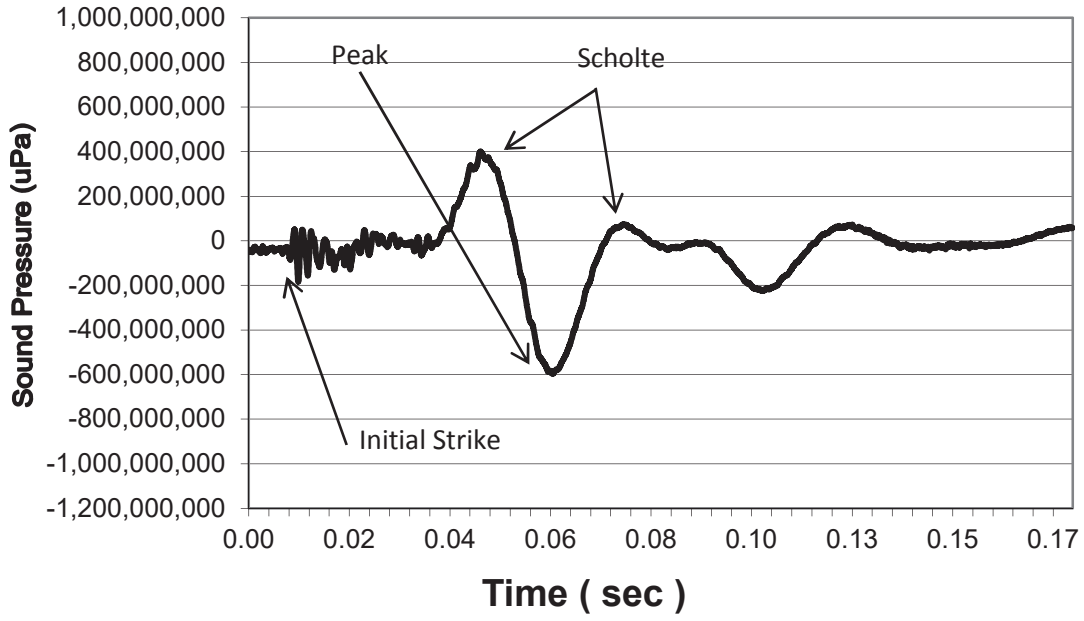
Pile 2

Pile 2 is located east of Pier 22, south of Pile 1 and north of Pile 3. This pile had an absolute attenuated peak value of 167 dB_{peak} at 10 meters. This pile did not exceed the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 165 B_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 24 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 182 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Scholte or Seismic Waves

Scholte or seismic waves are created at the boundary of the sediment water interface. It is a slow moving low frequency but generally high amplitude wave that is generated through the flexure of the substrate at the interface. In most cases for this project the actual peak value of the pile strike occurred within this Scholte wave portion of the waveform well after the initial strike (see example in Figure 9 and other examples in Appendix A). The peak value of the actual pile strike was often 2 dB to 28 dB lower than the amplitude of the Scholte wave. We typically see Scholte waves where pile driving occurs in relatively soft substrates but rarely does the amplitude exceed the peak pile strike amplitude as we saw for this project. It would be similar to driving a pile through a layer of Jell-O. The peak values of these types of Scholte waveforms are unlikely to cause injury to fish due to their relatively low frequency.

Figure 9: Example of a Scholte or seismic wave which was observed during post analysis of the SR 520 WABN pile monitoring data.



Pile 3

Pile 3 is located east of Pier 22, south of Pile 2 and north of Pile 6. This pile had an absolute attenuated peak value of 158 dB_{peak} at 10 meters. This pile did not exceed 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 is 155 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 6 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 172 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 4

Pile 4 is located immediately east of Pier 22, north of Pile 5 and west of Pile 6. This pile had an absolute attenuated peak value of 169 dB_{peak} at 10 meters. This pile did not exceed the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 157 B_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 33 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 174 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 5

Pile 5 is located immediately east of Pier 22, south of Pile 4 and west of Pile 7. This pile had an absolute attenuated peak value of 168 dB_{peak} at 10 meters. This pile did not exceed the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 153 B_{RMS}. The distance to the 169 dB_{peak}

threshold using the practical spreading model is 28 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 185 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 6

Pile 6 is located east of Pier 22, south of Pile 3 and east of Pile 4. This pile had an absolute attenuated peak value of 170 dB_{peak} at 10 meters. This pile exceeded the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 164 B_{RMS}. The distance to the 178 dB_{peak} threshold using the practical spreading model is 38 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 180 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 7

Pile 7 is located east of Pier 22, south of Pile 6 and east of Pile 5. This pile had an absolute attenuated peak value of 166 dB_{peak} at 10 meters. This pile did not exceed the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 162 dB_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 21 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 179 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 8

Pile 8 is located west of Pier 22 and north of Pile 9. This pile had an absolute attenuated peak value of 168 dB_{peak} at 10 meters. This pile did not exceed the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 160 B_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 28 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 170 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 9

Pile 9 is located west of Pier 22, south of Pile 8 and east of Pile 10. This pile had an absolute attenuated peak value of 165 dB_{peak} at 10 meters. This pile did not exceed the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 160 B_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 18 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 165 dB_{cSEL}.

Pile 10

Pile 10 is located west of Pier 22 and east of Pile 9. This pile had an absolute attenuated peak value of 166 dB_{peak} at 10 meters. This pile did not exceed the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 151 B_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 21 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 158 dB_{cSEL}.

Pile 11

Pile 11 is located immediately east of Pier 27, north of Pile 12 and west of Pile 13. This pile had an absolute attenuated peak value of 167 dB_{peak} at 13 meters. This pile did not exceed the 169 dB_{peak} threshold at 10 meters. The attenuated $RMS_{90\%}$ at 13 meters is 166 B_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 31 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 178 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 12

Pile 12 is located immediately east of Pier 27 and south of Pile 11. This pile had an absolute attenuated peak value of 169 dB_{peak} at 10 meters. This pile did not exceed the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 166 B_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 33 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 178 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 13

Pile 13 is located east of Pier 27 and east of Pile 11. This pile had an absolute attenuated peak value of 162 dB_{peak} at 10 meters. This pile did not exceed the 169 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 160 B_{RMS}. The distance to the 169 dB_{peak} threshold using the practical spreading model is 11 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 179 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile14

Pile 14 is located west of Pier 31 and south of Pile 15. This pile had an absolute attenuated peak value of 171 dB_{peak} at 10 meters. This pile did not exceed the 178 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 170 B_{RMS}. The distance to the 178 dB_{peak} threshold using the practical spreading model is 11 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 186 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 15

Pile 15 is located west of Pier 31 and north of Pile 14. This pile had an absolute attenuated peak value of 169 dB_{peak} at 10 meters. This pile did not exceed the 178 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 167 B_{RMS}. The distance to the 178 dB_{peak} threshold using the practical spreading model is 8 feet from the 10 meters location. The cSEL calculated based on each measured pile strike at 10 meters is 180 dB_{cSEL}. The recorded data cannot be used for these recordings are unique and it was difficult to calculate the single strike.

Pile 16

Pile 16 is located immediate east of Pier 33. This pile had an absolute attenuated peak value of 193 dB_{peak} at 10 meters. This pile exceeded the 178 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10

meters is 177 B_{RMS}. The distance to the 178 dB_{peak} threshold using the practical spreading model is 328 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 186 dB_{cSEL}.

Pile 17

Pile 17 is located east of Pier 32, north of Pile 19 and west of Pile 20. This pile had an absolute attenuated peak value of 200 dB_{peak} at 10 meters. This pile exceeded the 178 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 187 B_{RMS}. The distance to the 178 dB_{peak} threshold using the practical spreading model is 265 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 191 dB_{cSEL}.

Pile 18

Pile 18 is located east of Pier 32, south of Pile 18 and west of Pile 21. This pile had an absolute attenuated peak value of 196 dB_{peak} at 10 meters. This exceeded the 178 dB_{peak} threshold for this project. The attenuated $RMS_{90\%}$ at 10 meters is 179 dB_{RMS}. The distance to the 178 dB_{peak} threshold using the practical spreading model is 520 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 188 dB_{cSEL}.

Pile 19

Pile 19 is located east of Pier 32, north of Pile 21 and east of Pile 18. This pile had an absolute attenuated peak value of 198 dB_{peak} at 10 meters. This exceeded the 178 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 178 dB_{RMS}. The distance to the 178 dB_{peak} threshold using the practical spreading model is 707 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 189 dB_{cSEL}.

Pile 20

Pile 20 is located east of Pier 32, south of Pile 20 and east of Pile 19. This pile had an absolute attenuated peak value of 194 dB_{peak} at 10 meters. This exceeded the 178 dB_{peak} threshold. The attenuated $RMS_{90\%}$ at 10 meters is 176 dB_{RMS}. The distance to the 178 dB_{peak} threshold using the practical spreading model is 383 feet from the pile location. The cSEL calculated based on each measured pile strike at 10 meters is 185 dB_{cSEL}.

Table 5: Summary of Underwater Broadband Sound Levels for the SR 520 WABN Project East of Foster Island

Pier #	Pile #[3]	Date & Time	Pile Diameter (inches)	Hydrophone Range (m)	Hydrophone Depth (feet)	Total Number Of Strikes	Highest Absolute Peak[5] (dB)	$RMS_{90\%}$ ($dB_{}$)	Single Strike $SEL_{90\%}$ (dB)	Avg. Peak ± s.d. (Pascal)	Avg. RMS ± s.d. (Pascal)	Cumulative SEL (dB)
22	1	01/28/15 11:28 AM	30	10	2.5	258	191	172	156	1508±634	197±76	175
	2	01/28/15 11:42 AM	30	10	2.5	297	167	165	157	n/a	n/a	182[4]
	3	01/28/15 11:53 AM	30	10	2.5	335	158	155	147	n/a	n/a	172[4]
	4	01/31/15 9:40 AM	30	10	6.5	306	169	157	149	n/a	n/a	174[4]
	5	01/31/15 9:50 AM	30	10	6.5	232	168	153	161	n/a	n/a	185[4]
22	6[2]	01/31/15 10:03 AM	30	10	7	272	170	164	156	n/a	n/a	180[4]
	7	01/31/15 11:33 AM	30	10	7	282	166	162	154	n/a	n/a	179[4]
21	8	02/03/15 8:26 AM	30	10	7	93	168	160	150	n/a	n/a	170[4]
	9	02/03/15 8:34 AM	30	10	7	119	165	160	147	105±22	51±11	165
	10	02/03/15 8:52 AM	30	10	7	136	166	151	143	149±25	33±26	158
27	11	03/27/15 1:55 PM	30	13	5	108	167	166	158	n/a	n/a	178[4]
	12	03/27/15 2:10 PM	30	10	5	111	169	166	158	n/a	n/a	178[4]
	13	03/27/15 2:16 PM	30	10	5	142	162	160	157	n/a	n/a	179[4]
Between 30 & 31	14	03/28/15 11:03 AM	30	10	5	265	171	170	162	n/a	n/a	186[4]

Pier #	Pile #[3]	Date & Time	Pile Diameter (inches)	Hydrophone Range (m)	Hydrophone Depth (feet)	Total Number Of Strikes	Highest Absolute Peak[5] (dB)	$RMS_{90\%}$ ($dB_{}$)	Single Strike $SEL_{90\%}$ (dB)	Avg. Peak ± s.d. (Pascal)	Avg. RMS ± s.d. (Pascal)	Cumulative SEL (dB)
	15	03/28/15 11:15 AM	30	10	5	113	169	167	159	n/a	n/a	180[4]
33	17	4/11/15 9:37 AM	30	10	9	220	193	177	165	2672±654	486±89	186
32	18	04/12/15 11:56 AM	30	10	9	221	200	187	171	6792±1737	1538±512	191
	19	4/12/15 11:43 AM	30	10	9	306	196	179	167	4054±816	986±277	188
	20	4/12/15 11:01 AM	30	10	9	307	198	178	168	4540±979	830±204	189
	21	04/12/15 11:14 AM	30	10	9	191	194	176	165	2483±704	569±162	185

[1] Data not saved due to software malfunction.

[2] Battered Pile

[3] Data for pile number 16 was corrupted and it was not used

[4] cSEL for these piles were calculated using the total number of strikes method.

[5] The 169 dB_{peak} threshold was applied when monitoring began, but it was changed to 188 dB_{peak} during an ESA consultation that was in progress during the monitoring (based on the results of the WCB and WABN monitoring).

Daily Cumulative SEL

Where a waveform recording was available 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 6). Where it was not possible to calculate an $SEL_{90\%}$ for each individual pile strike the cSEL was calculated based on the total number of pile strikes. Where waveform recordings were not available due to software malfunctions daily cumulative SEL's (cSEL's) were calculated based on a conservative estimate calculated by subtracting 20 dB from the absolute peak level and adding this number to the product of the Log of the total number of strikes multiplied by 10.

Table 6: Summary of daily cumulative SEL's

Day	10M
West of Foster Island	
11/13/2014	185*
11/14/2014	161*
11/17/2014	184
11/18/2014	166
11/19/2014	171
11/20/2014	156*
12/15/2014	157*
12/16/2014	173*
12/19/2014	165*
02/04/2015	182*
02/05/2015	172*
East of Foster Island	
01/28/2015	186*
01/31/2015	190*
02/03/2015	174*
03/27/2015	183*
03/28/2015	184*
04/11/2015	186
04/12/2015	197

* - Calculations done using the total number of strikes.

The daily cumulative SEL values ranged from 156 to 197 dB at the 10 meter location.

Airborne Sound Levels

The airborne measurements were collected from the nearest location to the pile either on the shore or on the pile driving contractors raft between 8 meters (26 feet) and 32 meters (105 feet) from the piles. Ten minute measurements were collected along with 1-second time histories to attempt to capture the sound levels for most of the pile strikes. Since the meter is able to collect a measurement every one second and pile strikes occur approximately every 1.5 seconds some pile strikes were not able to be recorded.

The L_{Aeq} values west of Foster Island for the entire pile drive ranged between 95 dBA and 104 dBA at 50 feet and the L_{max} ranged between 106 dBA and 116 dBA at 50 feet (Table 7). The measured levels are all standardized to a distance of 50 feet which is standard for construction noise levels. Not all piles were monitored for airborne sound levels due to weather (rain) or insufficient staff to collect the measurements. However, we feel that the data collected is representative of the sound levels for all piles.

Table 7: Summary of 30-inch pile airborne sound levels collected between November 14, 2014 and February 4, 2015.

Pile #	Distance from Pile (m)	L_{Aeq} (dBA)	L_{Aeq} at 50 feet (dBA)	L_{max} (dBA)	L_{max} at 50 feet (dBA)
4	8	103	96	113	106
5	10	100	95	112	107
11	32	88	96	104	112
12	22	95	99	109	113
13	24	98	103	106	111
14	27	98	104	110	116
15	22	95	99	107	111
16	24	92	97	105	110
17	27	93	99	104	110
18	30	93	100	104	111

The time history plot of each individual pile strike measured for Pile 4 is shown in Figure 10. These results are typical of each pile measured. The L_{Aeq} sound levels for each pile strike for Pile 4 range between approximately 102 dBA and 107 dBA. Time history plots of the other piles measured are in Appendix B.

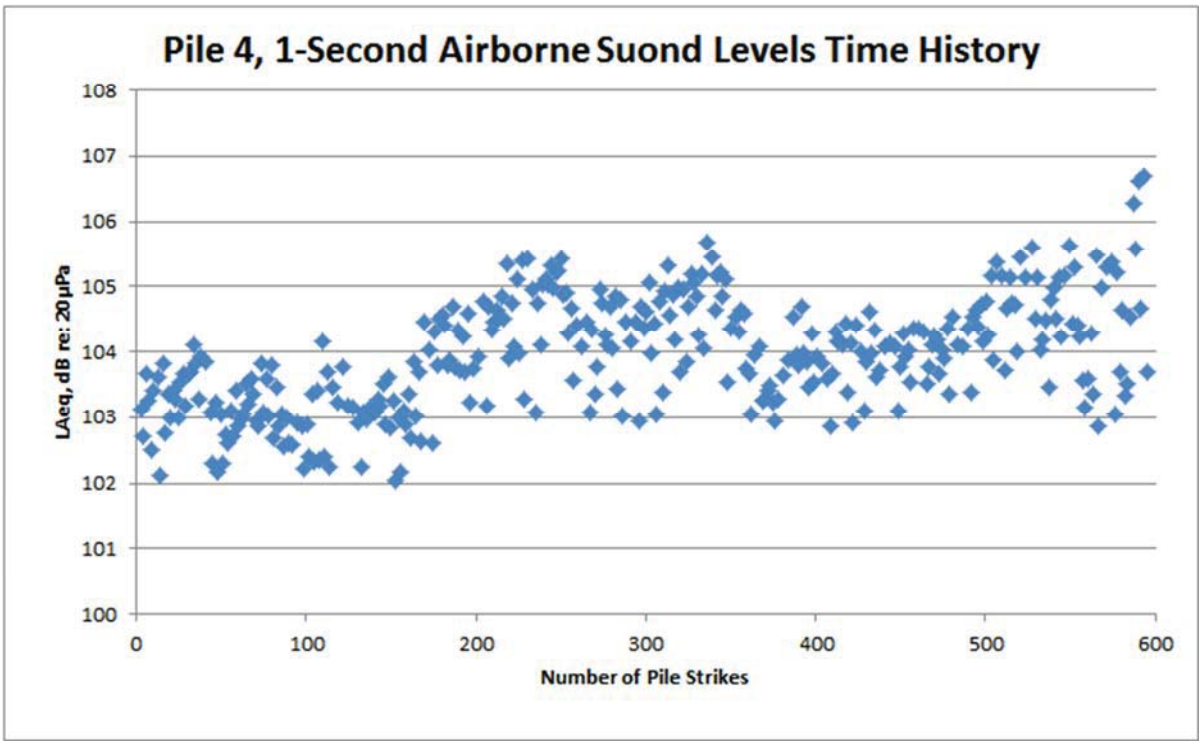


Figure 10: Time history of L_{Aeq} airborne sound levels for each pile strike for Pile 4, west of Foster Island.

The 1/3rd octave band frequencies were averaged for each pile strike of Pile 4 and plotted in Figure 11. The plot shows a relatively normal distribution of sound levels between 40 Hz and 20 kHz with the dominant frequency at approximately 0.8 kHz which is typical of impact pile driving sound levels. These results are typical of the other piles measured.

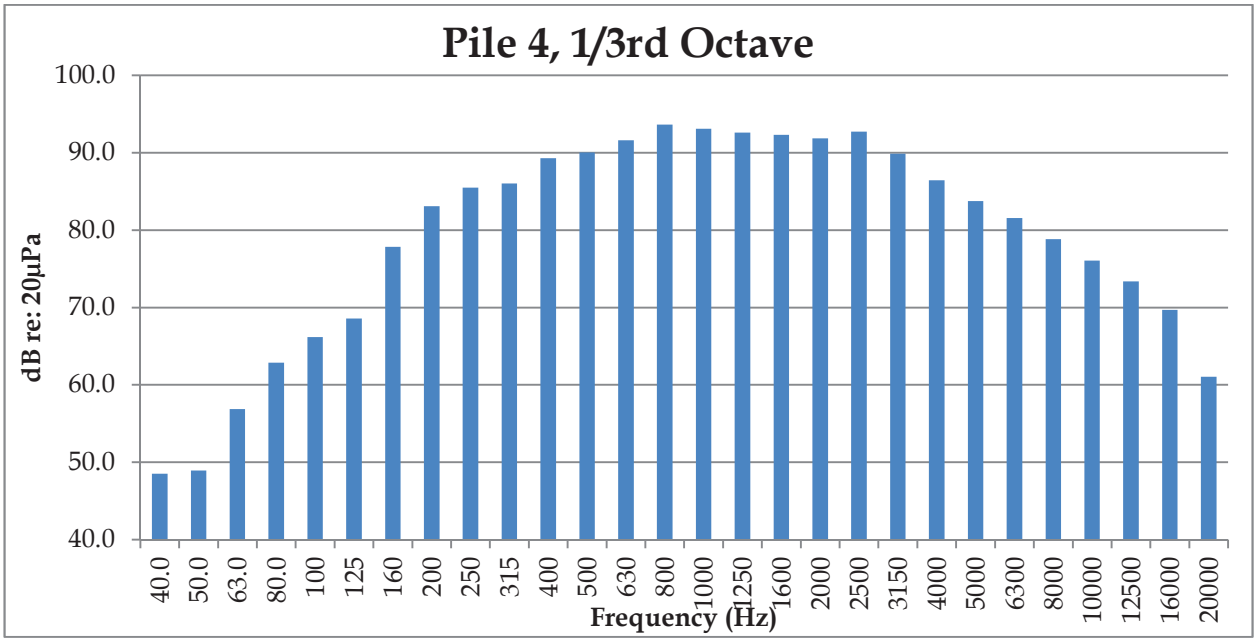


Figure 11: Average 1/3rd octave band frequencies (L_{Aeq}) for impact driving of Pile 4, west of Foster Island.

The L_{Aeq} values east of Foster Island for the entire pile drive ranged between 95 dBA and 100 dBA at 50 feet and the L_{max} ranged between 108 dBA and 112 dBA at 50 feet (Table 8). The measured levels are all standardized to a distance of 50 feet which is standard for construction noise levels. Not all piles were monitored for airborne sound levels due to weather (rain) or insufficient staff to collect the measurements. However, we feel that the data collected is representative of the sound levels for all piles.

Table 8: Summary of 30-inch pile airborne sound levels collected January 28, 2015, east of Foster Island.

Pile #	Distance from Pile (m)	L_{Aeq} (dBA)	L_{Aeq} at 50 feet (dBA)	L_{max} (dBA)	L_{max} at 50 feet (dBA)
1	11	99	95	112	108
2	15	100	100	111	111
3	18	98	100	110	112

CONCLUSIONS

A total of 40, 24 to30-inch steel piles, 20 piles west of Foster Island and 20 piles east of Foster Island were monitored for the construction of the SR 520 West Approach Bridge North project. The underwater sound levels analyzed, produced the following results.

West of Foster Island:

- Peak underwater attenuated sound levels at 10 meters varied in a range between 161 dB_{Peak} and 181 dB_{Peak} .
- The measured $RMS_{90\%}$ levels of the 10 meter measurements ranged between 145 dB_{RMS} and 169 dB_{RMS}.
- Cumulative Sound Exposure Levels (cSEL), for all piles driven at 10 meters on a particular day, ranged between 156? dB_{cSEL} and 197 dB_{cSEL}.
- The distance measured from the pile location to the 169 dB_{peak} threshold ranged between 10 feet and 300 feet.

East of Foster Island:

- Peak underwater attenuated sound levels at 10 meters varied in a range between 158 dB_{Peak} and 200 dB_{Peak} .
- The measured $RMS_{90\%}$ levels of the 10 meter measurements ranged between 151 dB_{RMS} and 179 dB_{RMS}.
- Cumulative Sound Exposure Levels (cSEL) for all piles driven at 10 meters on a particular day, the daily cSEL values ranged between 156 dB_{SEL} and 197 dB_{cSEL}.
- The distance measured from the 10 meter location to the 169 dB_{peak} threshold ranged between 6 feet and 1,057 feet.
- The distance measured from the 10 meter location to the 178 dB_{peak} threshold ranged between 8 feet and 961 feet.

Thirteen 30-inch piles were monitored for airborne sound levels during impact driving. The measurements produced the following results.

- L_{Aeq} sound levels were measured to be between 95 and 104 dB re: 20 µPa at 50 feet.
- L_{max} levels ranged between 106 and 116 dB re: 20 µPa at 50 feet.