Concrete Pier Demolition Underwater Sound Levels: SR 303 Manette Bridge Project

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EXECUTIVE SUMMARY

This technical report describes the data collected during demolition operations of Pier 5Aa and Pier 6 with two different sizes of Hoe Ram equipment. This demolition project has the objective to clear the channel under the new Manette Bridge on early July 2012 to continue through the end of December 2012.

Previous reports describing the waveform for hoe ram demolition in water have cited Dolat (1997). In his paper Dolat converted the measurements from individual hoe ram strikes from concrete bridge piers into total energy and then reported these results as a modeled simple sine wave to simplify his discussion. Many reports since have misinterpreted his results to indicate that the hoe ram sound was more of a continuous sound similar to vibratory pile installation. Reporting impact or impulsive sound levels using current methods used for vibratory or continuous sound levels could provide misleading results and is inconsistent with the current practices for reporting underwater noise levels in Washington State (NMFS, 2012a, 2012b and 2012c). This report shows that the hoe ram waveform is comparable to impact pile driving waveforms and were analyzed accordingly.

Two of the 8 concrete Manette Bridge piers demolished were measured during hoe ram demolition operations (Table 1). The peak sound levels measured ranged between 194 and 205 when hoe ram work occurred above the Ordinary High Water Mark (OHWM). The cumulative Sound Exposure Level (SEL_{cum}) for piers 5A and 6 did exceed the interim threshold of 187 dB_{SEL} when calculated using the number of strikes and the actual measured SEL value for each impact strike.

Table 1: Summary of Pier Demolition Results, SR 303 Manette Bridge Demolition Project.

Pier Number	Date	Mitigation Type	Peak (dB)	Average Peak (dB)	Average RMS (dB)	Single Strike SEL (dB)	Interim Cumulative SEL Criteria (dB)	Cumulative SEL (dB)
5A	7/03/2012	None	189	183	173	160	187	195
6	7/10/2012	None	205	197	186	171	187	196

INTRODUCTION

This technical report presents results of underwater sound levels measured during the demolition operation of two concrete bridge piers from the old Manette Bridge which has been replaced by a new structure in 2011.

The contractor used hoe rams to perform the demolition of the concrete piers. The former bridge's piers consisted of concrete of different ages due to retrofits and repairs which occurred through the life of the former bridge. The demoliton also demolished the steel bar components of the piers. The measurements included in this report are those obtained during the demolition of portion of the piers above the water Ordinary High Water Mark (OHWM) and not below the waterline. The measurements occurred at the time of the lowest tide. The project site is located on the Kitsap Penisula near the city of Bremerton, Washington. (Figure 1).

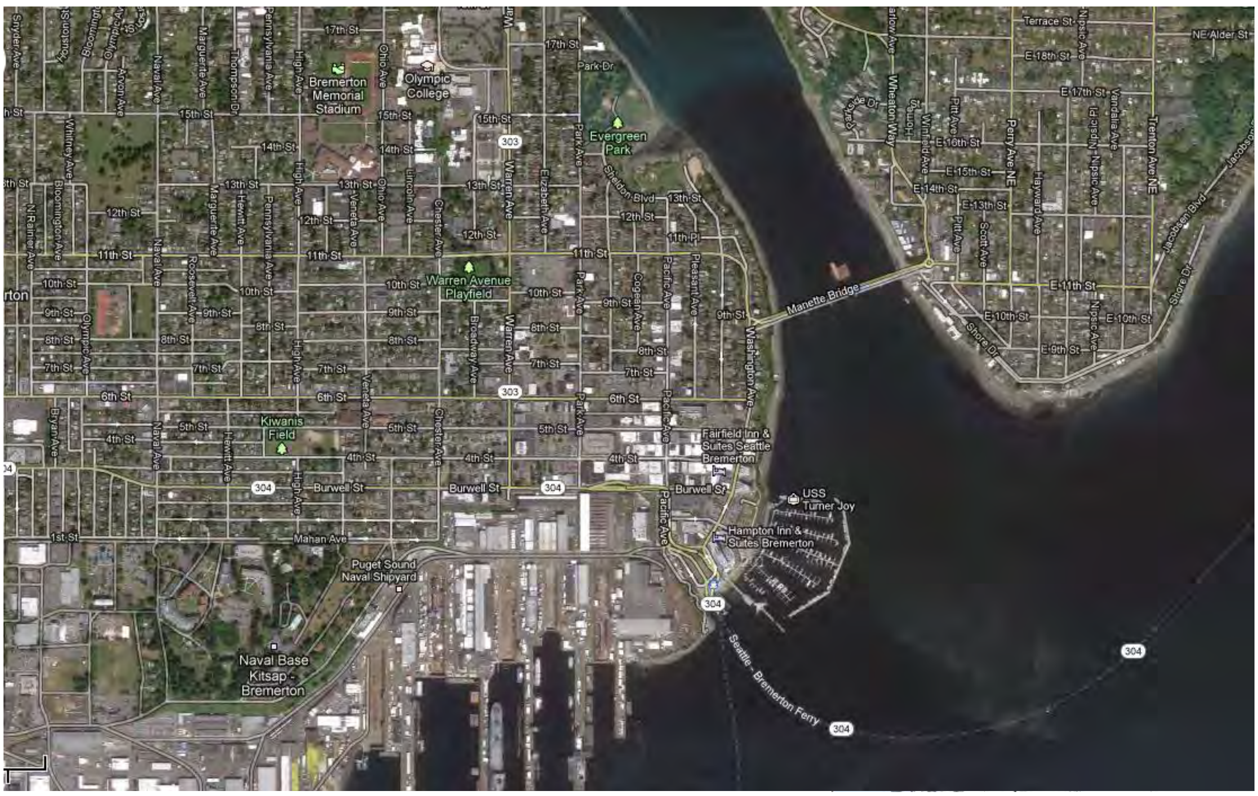


Figure 1: Location of SR 303 Manette Bridge Demolition Project.

- Project consisted of demolishing the eight remaining concrete piers at Manette Bridge,(Figure 2)
- Hydrophone depths at the monitoring locations varied from 6 to 14 feet deep depending on the tidal flux and the pier.
- Piers 5A and 6 demolition were measured during the low tidal flux.

Figure 2: Location of the old concrete piers relative to the new Manette Bridge.

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.

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

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)

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 sound exceeds the level in any single 1/3-octave band.

METHODOLOGY

Equipment

The hydrophones were deployed from a small boat containing the monitoring equipment and were stationed with anchors at the predetermined distances of 10 meters and 3 H from the source, where H is the depth of water at the source. The boat was not able to be anchored during both monitoring locations due to the tidal current (Figure 3).

Figure 3: Monitoring station (boat = green dot) during hydrophone deployment (red dots).

Underwater sound levels were measured near the piers using two Reson TC 4013 hydrophones deployed on a nylon cord off the side of the boat at each pier. The two hydrophones were positioned, one at a distance of 10 meters from the hoe ram and mid-water and one at 3H and at a depth of 10 or 14 feet (depending on tide) from the individual piers being monitored. The measurement system includes a Brüel and Kjær Nexus type 2692 4-channel signal conditioner, which kept the high underwater sound levels within the dynamic range of the signal analyzer Figure 4. The output of the Nexus signal conditioner is received by a Bruel and Kjaer Photon 4-channel signal spectrum analyzer that is attached to a Dell ATG laptop computer similar to the one shown in Figure 4.

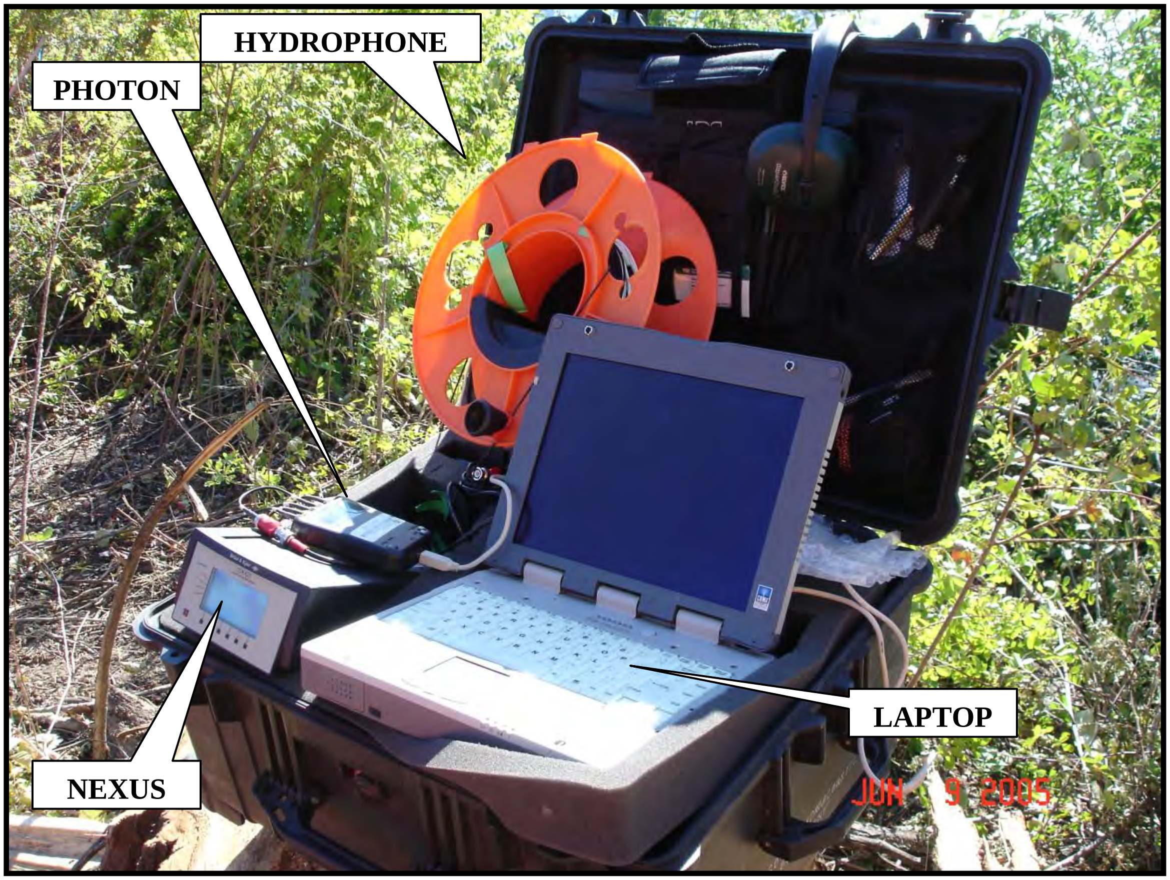


Figure 4: Near field acoustical monitoring equipment

The waveform of the hoe ram operation was captured as a signal file for processing later. The system and software calibration is checked annually against a NIST traceable standard.

Signal analysis software provided with the Photon was set at a sampling rate of one sample every 7.6 µs (51,200 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 hoe ram 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 pier.

Hydrophone Location

The location of the hydrophones is determined by allowing a clear line of sight between the pier and the hydrophone, with no other structures nearby. The distance from the pile to the hydrophone location was measured using a Bushnell Yardage Pro rangefinder. The hydrophone was attached to a weighted nylon cord anchored with 20 pound weights because the tidal current within the channel was relatively rapid at the time of the monitoring. The cord and hydrophone cables were lowered at 10 meters and mid-water depth and 3H and a depth of 80% of the depth at 3H from the source between the pier and the boat as shown in Figure 5, where H is the depth of the water at the pile.

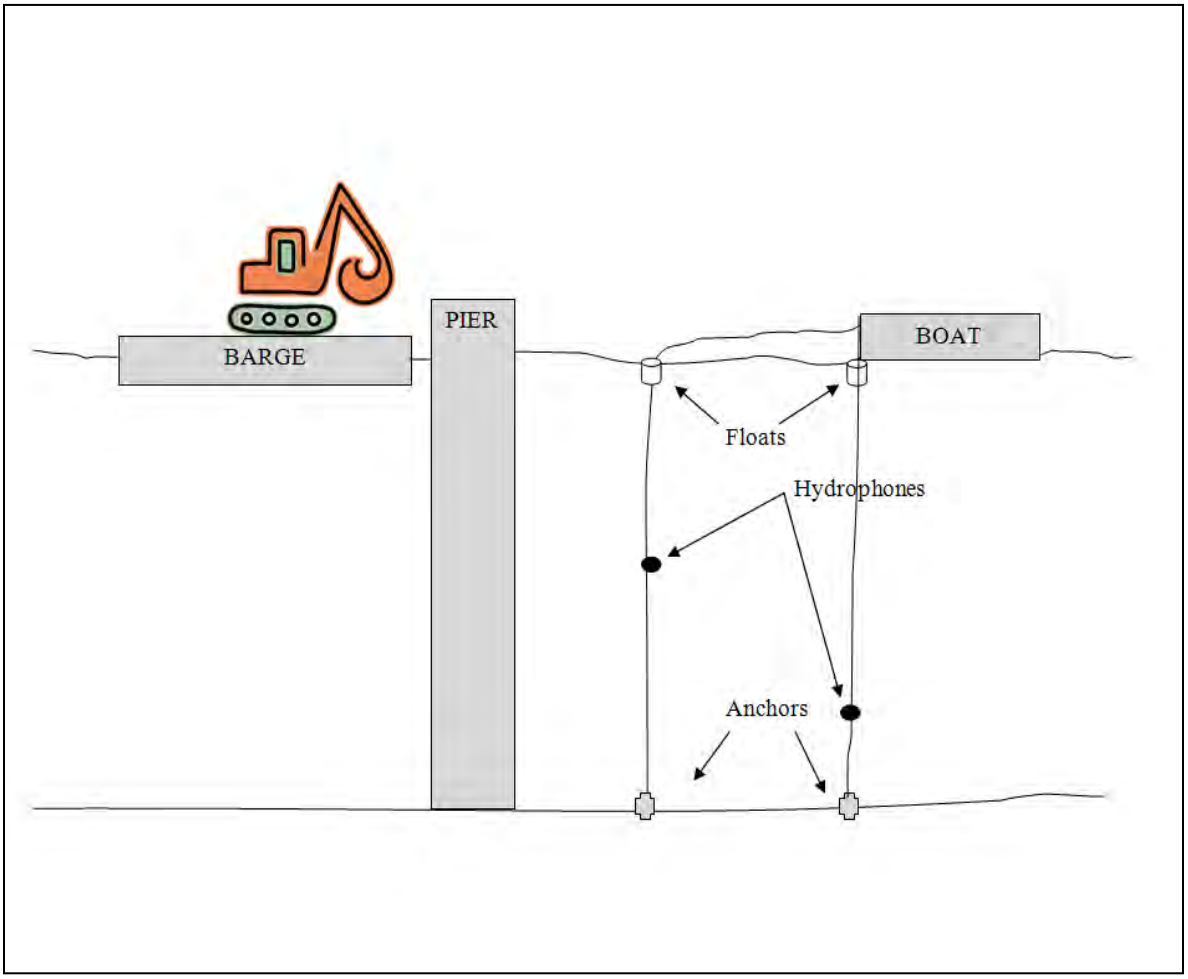


Figure 5: Diagram of hydrophone deployment configuration.

SEL

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

$$SEL_{90\%} = RMS_{90\%} + 10\ LOG(\tau) \qquad \text{(eq. 1)}$$

Where τ is the 90% time interval over which the $RMS_{90\%}$ value is calculated for each impact strike.

Initial negotiations with the National Marine Fisheries (NMFS) and U.S. Fish and Wildlife Service (USFWS) did not include 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 it 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. The results in this report clearly show that the waveform from a hoe ram is nearly identical to impact pile driving waveforms. Therefore, the interim thresholds of 206 dB_{peak} and 187 dB_{SELcum} apply here.

Pier 5A

A hoe ram was used to demolish Pier 5A which was positioned on top of wood planks so the hoe ram arm would be able to reach the pier structure from the beach (Figure 6). The hoe ram was then driven as close to the structure as possible to maintain stability and demolish the concrete that later would be scooped onto the barges for transport off site. In this application the maximum energy output from the hoe ram could only be sustained for a few seconds at a time due to the need to maintain stability on the wood planks. We are uncertain of the energy rating for the hoe ram used on Pier 5A but it was smaller than that used for pier 6. We estimate that the actual operation of the hoe ram was only 50% of this maximum energy for most of the operation. The substrate consisted of relatively soft sandy silt.

Figure 6: View of the Demolition of Pier 5A

Pier 6

To demolish Pier 6, a hoe ram was set onto a full size barge where it was able to reach the pier. The impact driver of the hoe ram was rated at a maximum of 9,293 foot pounds. The substrate consisted of relatively soft sandy silt.

RESULTS

Underwater Sound Levels

The waveforms obtained from the hoe ram shows that they are similar to impact type waveforms. Initially a literature search indicated that this type of signal would be similar to the vibratory pile driving waveform (Dolat, 1997), however, our findings are contrary to those assumptions. Unfortunately, due to a software malfunction the hydrophone deployed at 3H did not collect any data. However, due to the relatively shallow water the distance between the 10 meter location and the 3H location was only 3 feet for Pier 5A and 18 feet for Pier 6 and so the sound levels for Pier 5A would be essentially the same.

Pier 5A

Pier 5A was demolished using a hoe ram above the OHWM. No mitigation was used nor proposed for this work. A grab mounted to a crane on the barge was used to collect the concrete that was demolished at each pier (Figure 7).

Figure 7: Machinery to be used for debris removal of debris after Ram Pier 5A Demolition

The results of monitoring for Pier 5A are shown in Table 2:

- The highest absolute peak from the hydrophone at 33 feet (10 meters) from the pier and mid-water depth (6 feet) is 189 dB_{peak} and did not exceed the 206 dB_{peak} interim threshold for fish.
- The average RMS at 33 feet and mid-water depth is 173 dB_{RMS} which exceeds the 160 dB_{RMS} threshold for marine mammals.
- The highest single strike Sound Exposure Level (SEL) for the peak strike at 33 feet and mid-water depth is 160 dB_{SEL}.

Based on the 3022 impact strikes that were measured the cumulative SEL is 195 dB_{SEL} which is above the 187 dB_{SEL} interim threshold for fish (Figure 8). Demolition of pier 5A continued after monitoring ceased.

Calculating the cumulative SEL based on the $SEL_{90\%}$ for each pile strike the cumulative SEL is 189 dB_{SEL} which also exceeds the 187 dB_{SEL} interim threshold for fish (Figure 8).

The waveform analysis for Pier 5A indicates that there was a rise time of 5.4 milliseconds.

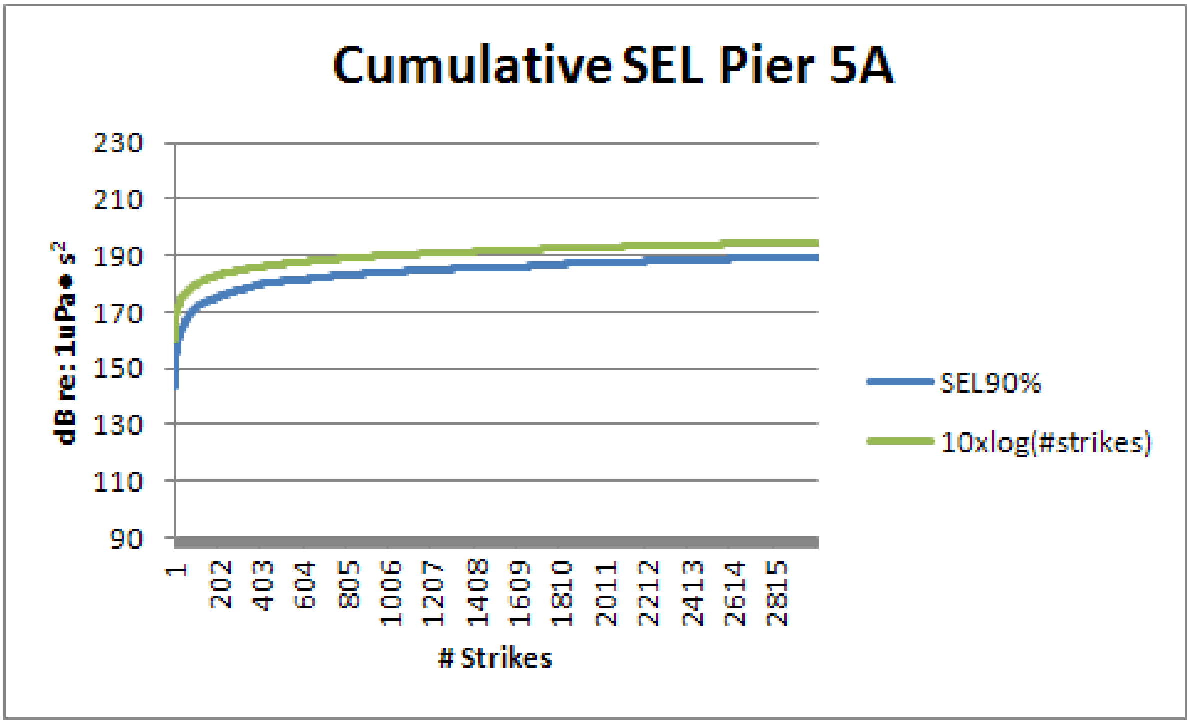


Figure 8: Cumulative SEL plot for Pier 5A showing the cumulative plot for SEL values calculated for each pile strike (blue) versus the SEL plot based on the total number of strikes (green).

The 1/3rd Octave frequency distribution calculated over the duration of the measurement for Pier 5A indicates a dominant frequency at 1000 Hz (Figure 9).

Table 2: Summary of Underwater Sound Levels for the SR 303 Manette Bridge Pier Demolition Project

Pier	Date	Hydrophone Range (feet)	Hydrophone Depth (feet)	Mitigation Type	Total Number Of Strikes[2]	Highest Absolute Peak (dB)	Interim Peak Threshold (dB)	Avg. dB_{RMS}	Avg. dB_{peak}	Highest Single Strike SEL (dB)	Rise Time (millesec.)	Interim Cumulative SEL Threshold (dB)	Cumulative SEL (dB)[4]
5A[3]	7/3/2012	33	6	None	3012	189[1]	206	173	183	160	5.4	187	195
6	7/10/2012	33	8.5	None	707	205	206	186	197	171	2.8	187	196

1 – Peak represents underpressure.
2 – Total number of strikes represent only those strikes counted during monitoring but demolition of pier lasted much longer.
3 – Pier demolish above the Ordinary High Water Mark (OHWM).
4 – Based on total number of strikes measured.

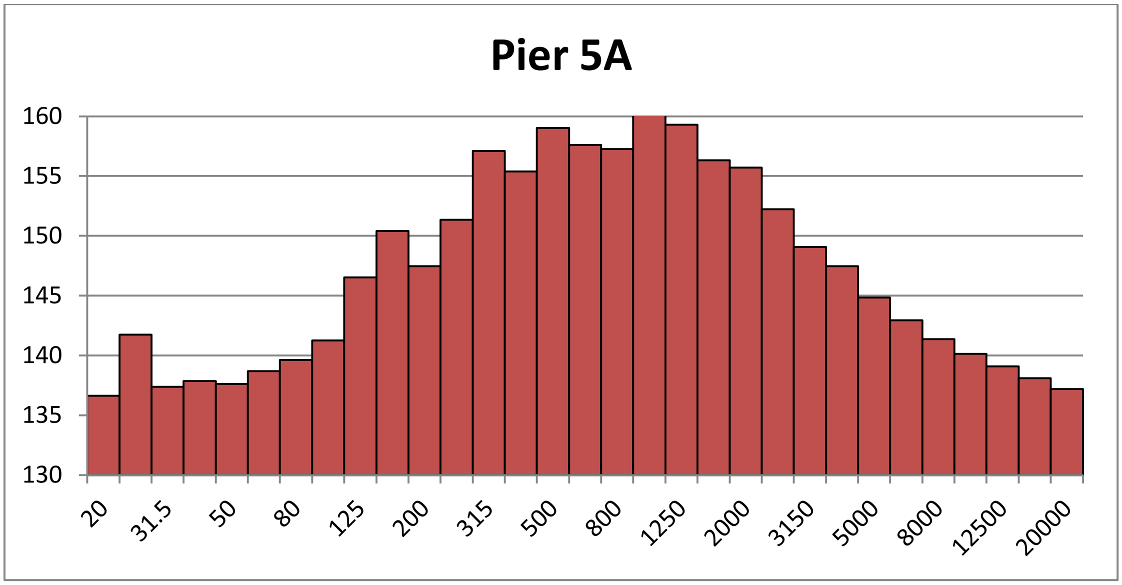


Figure 9: 1/3rd Octave frequency distribution for Pier 5A demolition.

Pier 6

The demolition operation at Pier 6 began approximately 10 feet above the OHWM. The hydrophone for Pier 6 was located 33 feet (10 meters) from the pier and mid-water depth.

The results of monitoring for Pier 6 (Table 2) indicate:

- The highest absolute peak at the hydrophone at a distance of 33 feet and depth of 8.5 feet (mid-water) is 205 dB_{peak} and did not exceed the 206 dB_{peak} interim threshold.
- The average RMS at a distance of 33 feet and depth of 8.5 feet depth is 186 dB_{RMS}.
- The highest single strike SEL for the peak strike at a distance of 33 feet and depth of 8.5 feet water depth is 171 dB_{SEL}.

The cumulative SEL did exceed the 187 dB SEL_{cum} threshold after 190 strikes. The SEL was estimated for each individual pile strike by calculating the $SEL_{90\%}$ for each pile strike. Plots of the cumulative SEL values for each pile strike (Figure 10, blue line) compares the calculated cumulative SEL based on the number of strikes (Figure 10, green line). The two methods differ only slightly in this instance. Both methods of calculating the cumulative SEL exceeded the 187 dB SEL_{cum} threshold.

The waveform analysis for Pier 6 indicates that there was a rise time of 2.8 milliseconds.

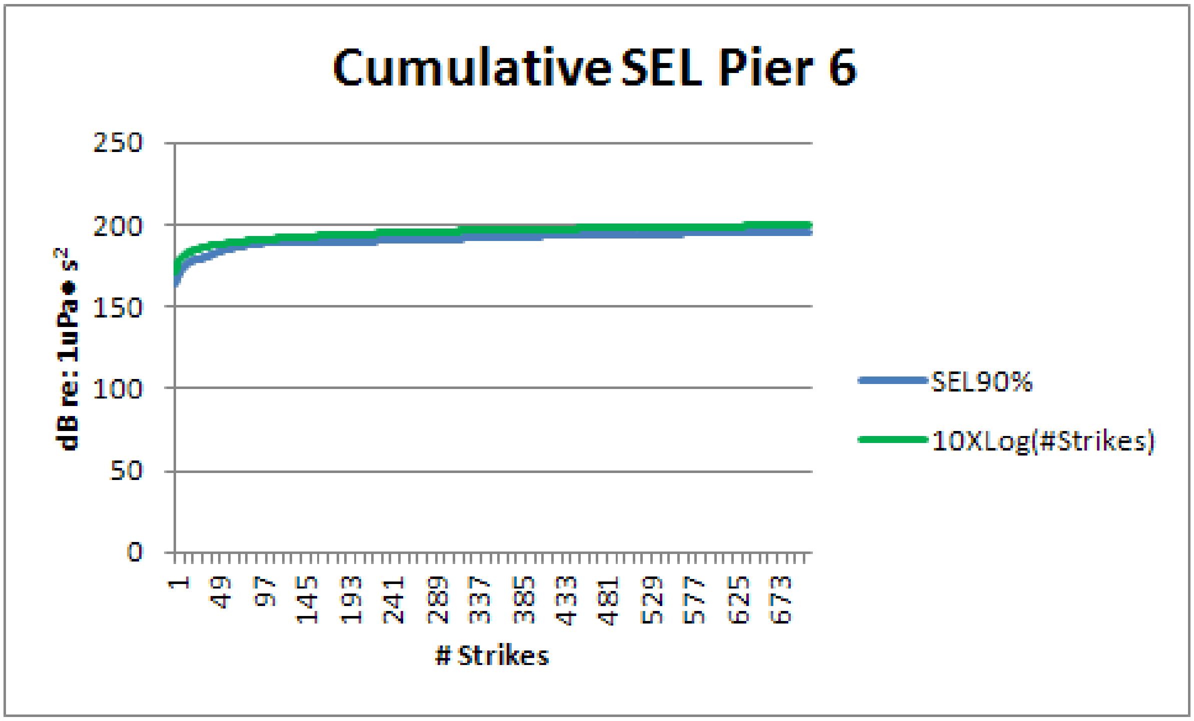


Figure 10: Cumulative SEL plot for Pier 6 showing cumulative for SEL values calculated for each impact strike (blue) versus the SEL plot based on the total number of strikes (green)

The 1/3rd Octave frequency distribution calculated over the duration of the measurement for Pier 6 indicates a dominant frequency occurring at 1600 Hz (Figure 11). There is a secondary peak at 100 Hz. This is similar to the 1/3rd Octave results for Pier 5A.

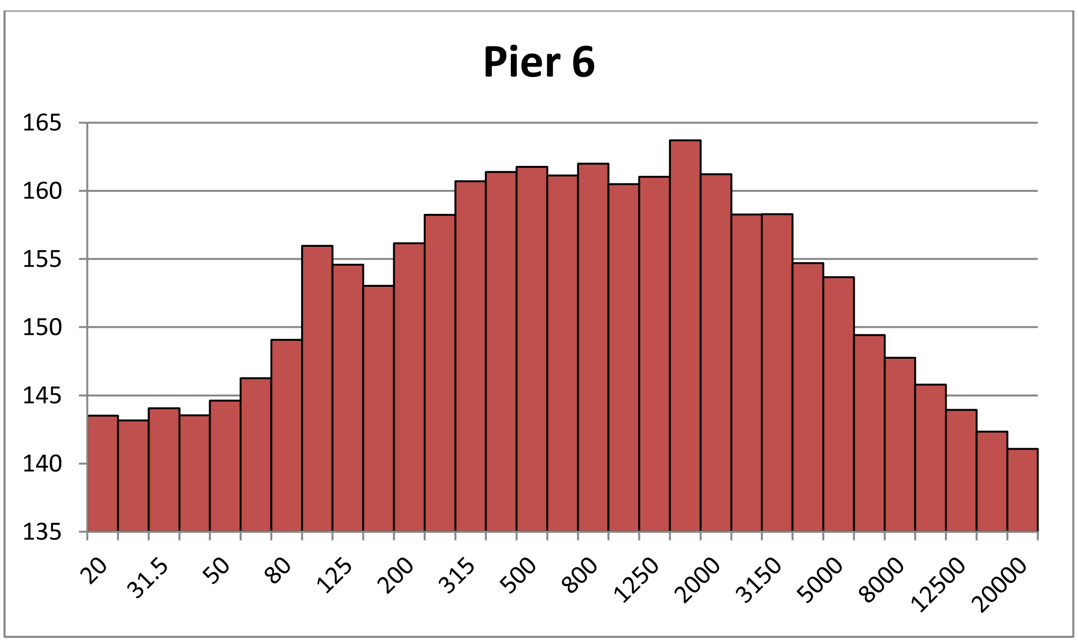


Figure 11: 1/3rd Octave frequency distribution for Pier 6 demolition

CONCLUSIONS

A total of two concrete piers were monitored for a portion of their demolition activities at Manette Bridge.

- Peak underwater sound levels for demolition of concrete piers ranged between 189 dB_{Peak} and 205 dB_{Peak}.
- Average RMS levels ranged between 173 dB_{RMS} and 186 dB_{RMS}.
- Cumulative Sound Exposure Levels (SEL) were calculated both for individual pile strikes and then summed as well as calculated using the peak strike SEL value and the total number of strikes.
- The hoe ram used for Pier 6 was larger and produced higher sound levels.
- Piers 5A and 6 exceeded the cumulative SEL for fish.

REFERENCES

Dolat, S.W. 1997. Acoustic measurements during the Baldwin Bridge Demolition. Sonalysts, Inc. Waterford, CT 06385.

NMFS, 2012a. Guidance Document: Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon. Memorandum: NMFS Northwest Fisheries Science Center – Conservation Biology Division and Northwest Regional Office – Protected Resources Division, January 31, 2012. http://www.nwr.noaa.gov/Marine-Mammals/MM-sound-areas.cfm

NMFS, 2012b. Guidance Document: Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals. Memorandum: NMFS Northwest Fisheries Science Center – Conservation Biology Division and Northwest Regional Office – Protected Resources Division, January 31, 2012. http://www.nwr.noaa.gov/Marine-Mammals/MM-sound-areas.cfm

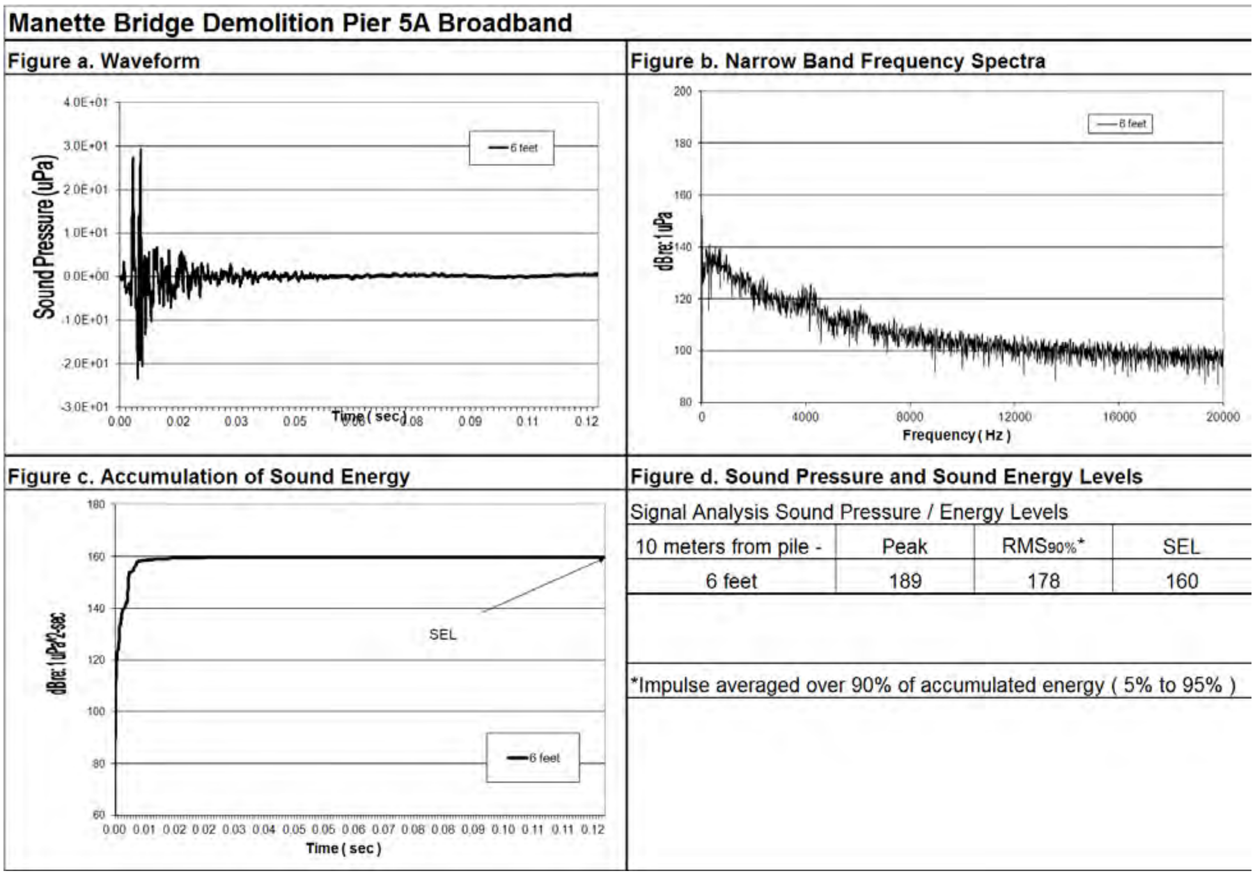
NMFS, 2012c. Guidance Document: Sound Propagation Modeling to Characterize Pile Driving Sounds Relevant to Marine Mammals. Memorandum: NMFS Northwest Fisheries Science Center – Conservation Biology Division and Northwest Regional Office – Protected Resources Division, January 31, 2012. http://www.nwr.noaa.gov/Marine-Mammals/MM-sound-areas.cfm

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33(4): 411-521. http://www.nwr.noaa.gov/Marine-Mammals/MM-sound-areas.cfm

APPENDIX A

Waveform Analysis Figures

Pier 5A, 20 Hz to 20 kHz



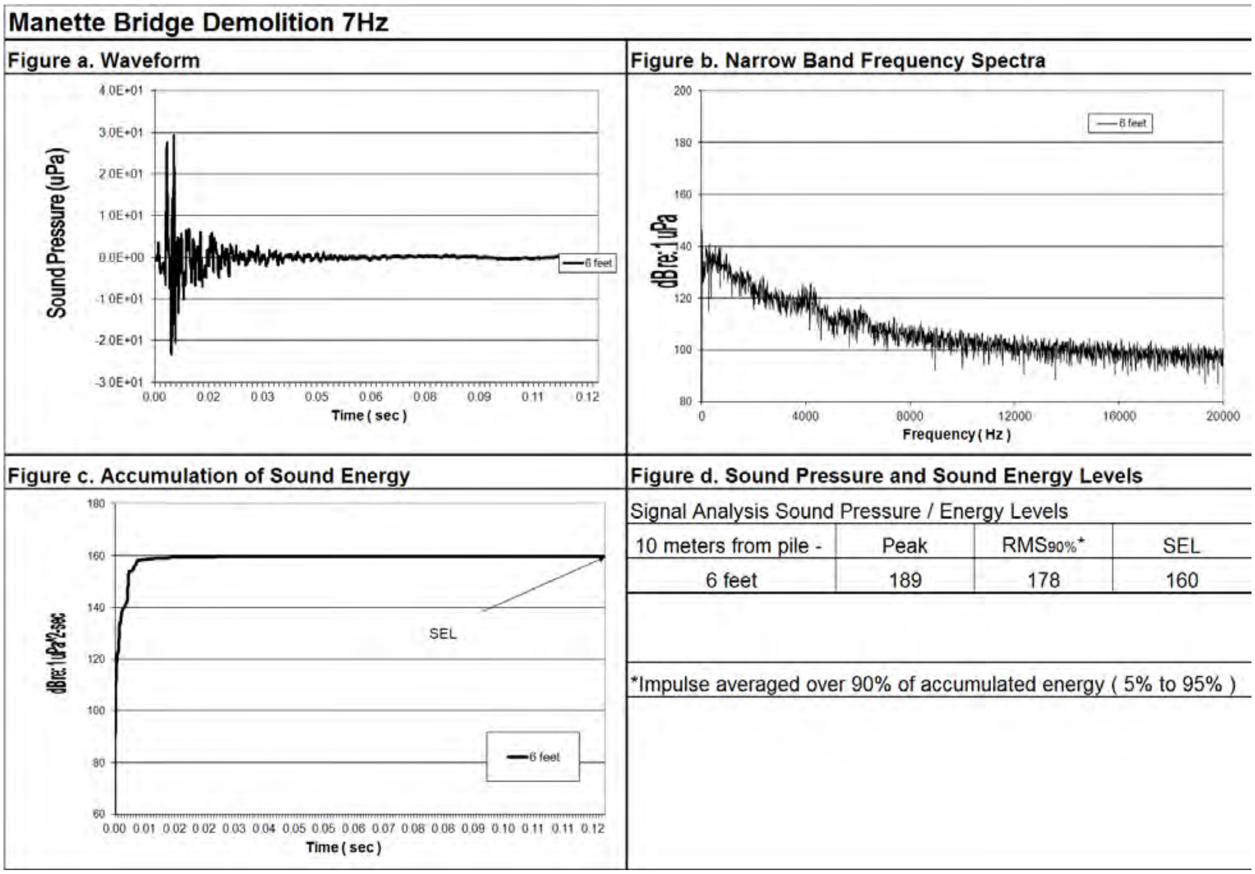
Signal Analysis Sound Pressure / Energy Levels

10 meters from pile -	Peak	RMS90%*	SEL
6 feet	189	178	160

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

Figure 12: Waveform analysis of Pier 5A sound pressure levels, using hoe ram broadband without filtered frequencies

Pier 5A, 7 Hz to 20 kHz

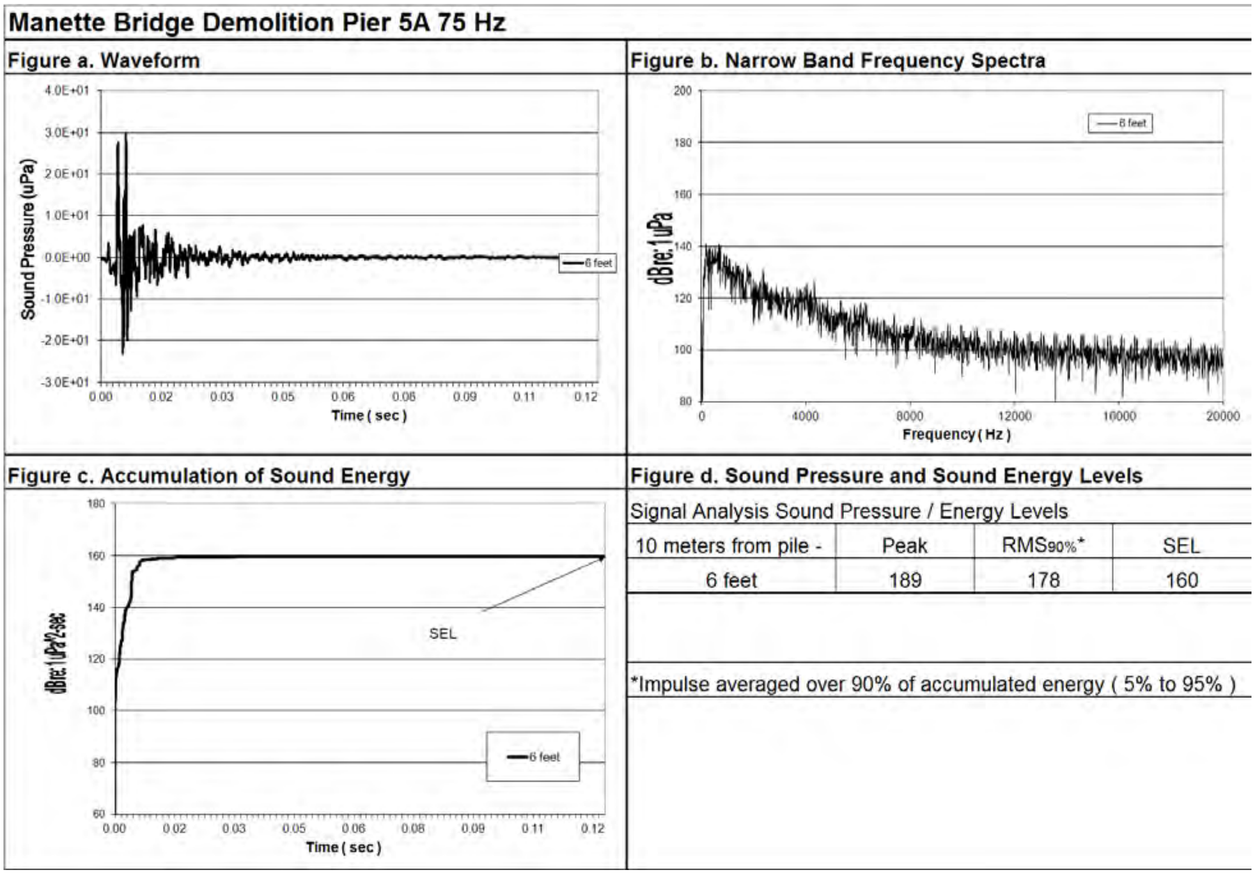


10 meters from pile -	Peak	RMS90%*	SEL
6 feet	189	178	160

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

Figure 13: Waveform analysis of Pier 5A demolition (7Hz to 20 kHz)

Pier 5A, 75 Hz to 20 kHz



10 meters from pile -	Peak	RMS90%*	SEL
6 feet	189	178	160

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

Figure 14: Waveform analysis of Pier 5A (75 Hz to 20 kHz).

Pier 5A, 150 Hz to 20 kHz

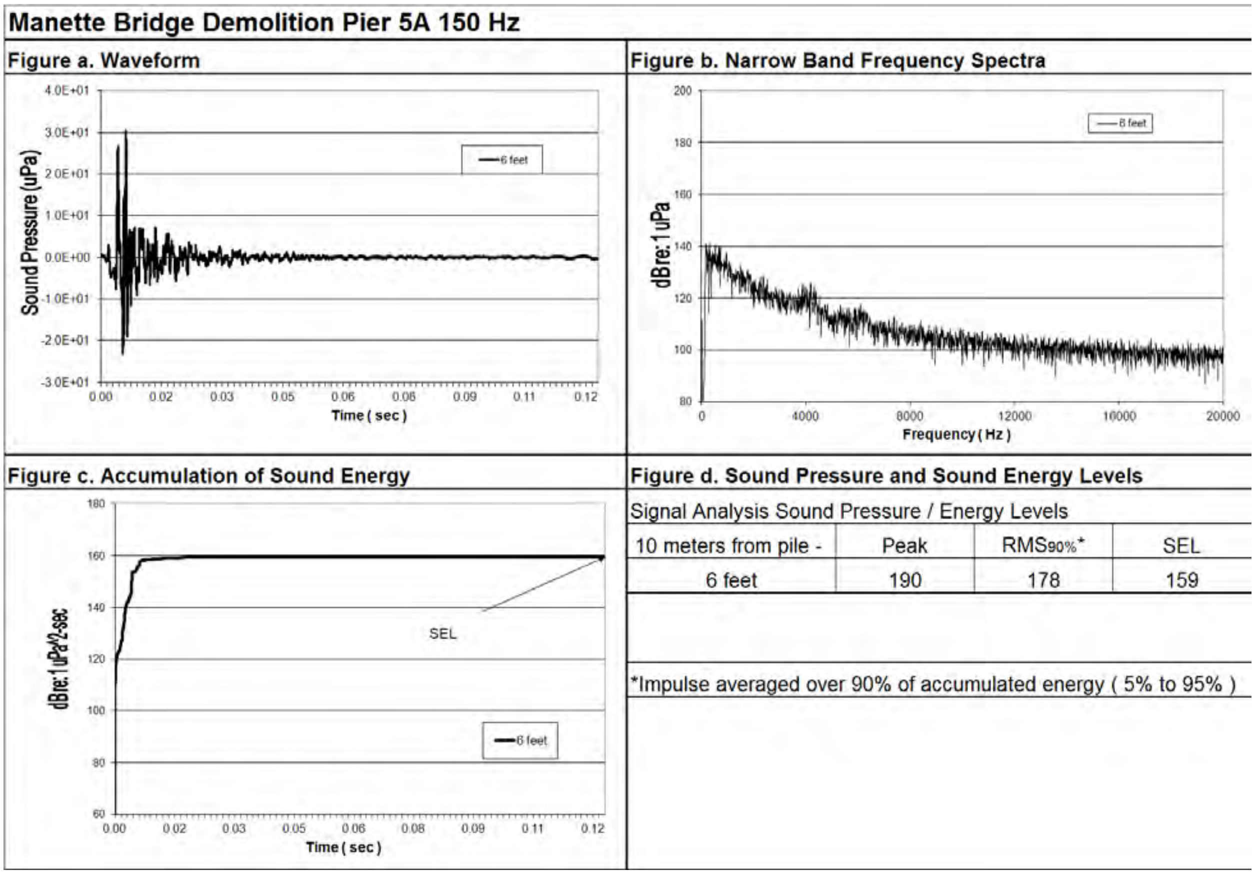
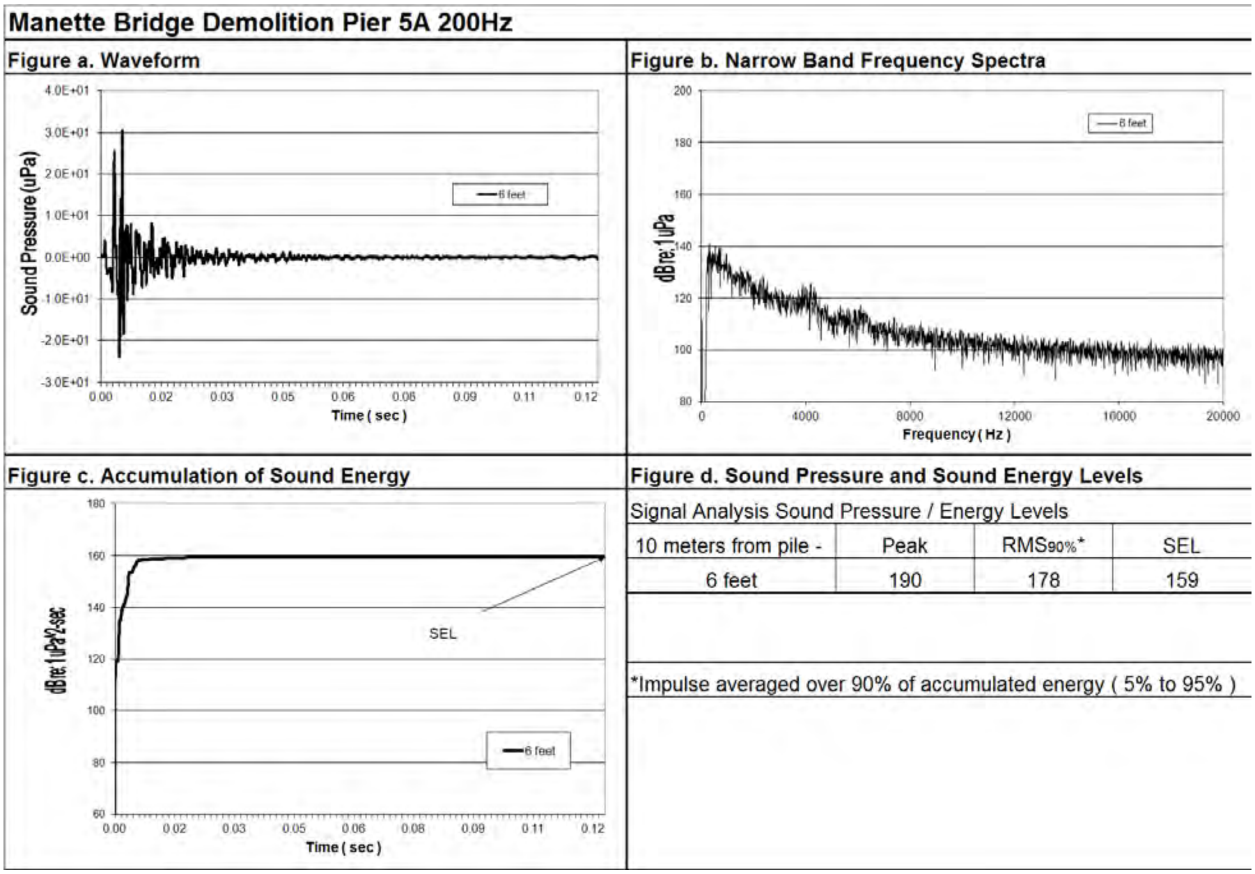


Figure 15: Waveform analysis of Pier 5A (150 Hz to 20 kHz).

Pier 5A, 200 Hz to 20 kHz



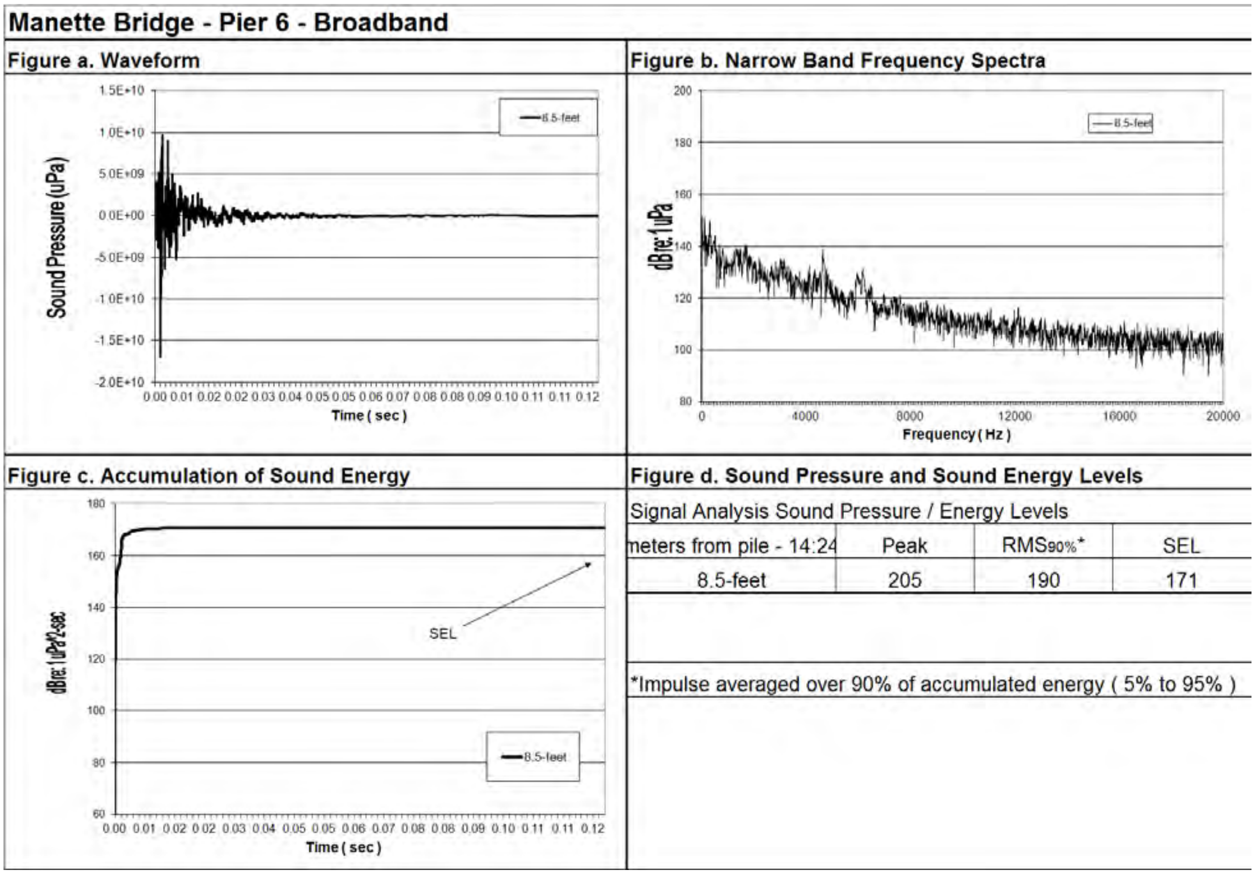
Signal Analysis Sound Pressure / Energy Levels

10 meters from pile -	Peak	RMS90%*	SEL
6 feet	190	178	159

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

Figure 16: Waveform analysis of Pier 5A, (200 Hz to 20 kHz).

Pier 6, 20 Hz to 20 kHz



meters from pile - 14:24	Peak	RMS90%*	SEL
8.5-feet	205	190	171

Figure 17: Waveform analysis of Pier 6 demolition using hoe ram T70 (20 Hz to 20 kHz)

Pier 6, 7 Hz to 20 kHz

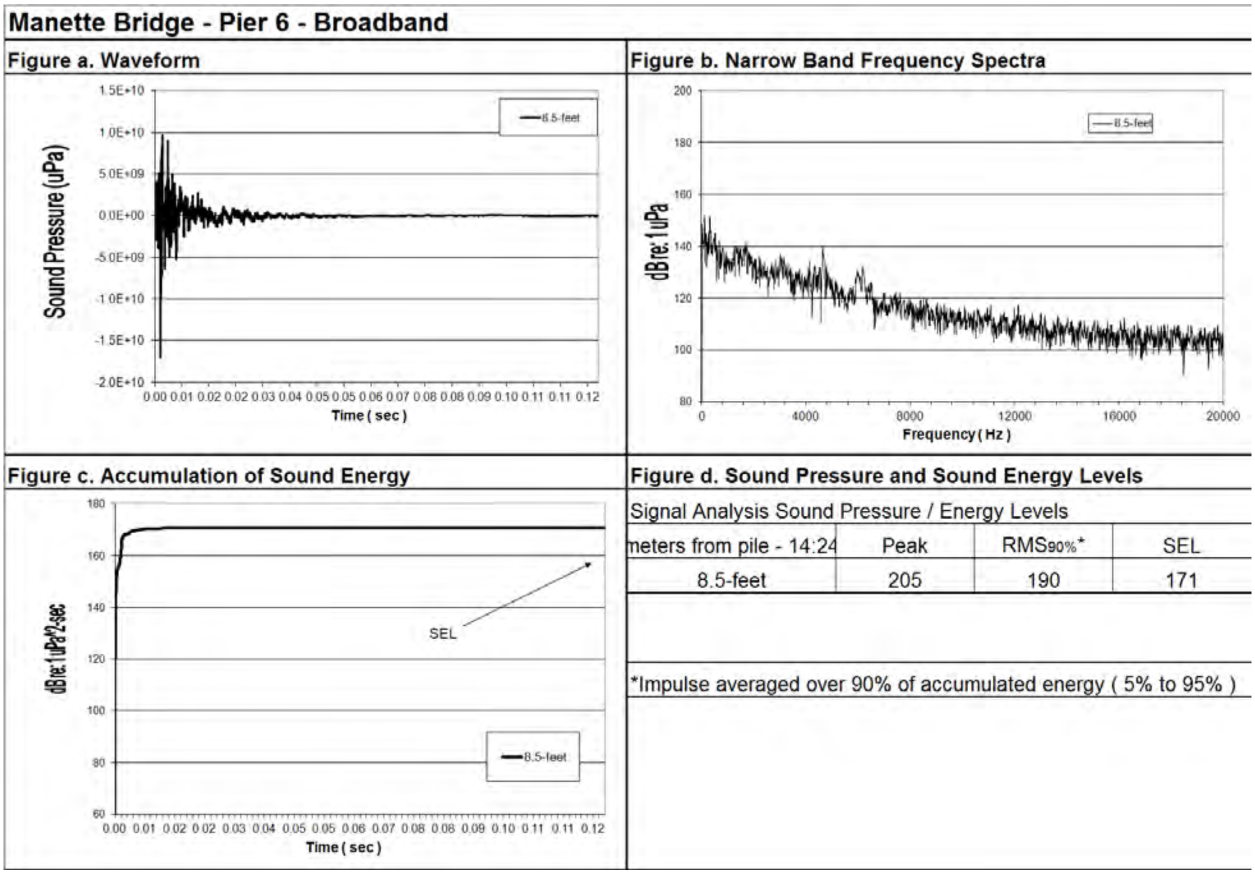


Figure 18: Waveform analysis of Pier 6, (7 Hz to 20 kHz).

Pier 6, 75 Hz to 20 kHz

Manette Bridge - Pier 6 - 75 Hz

Figure a. Waveform

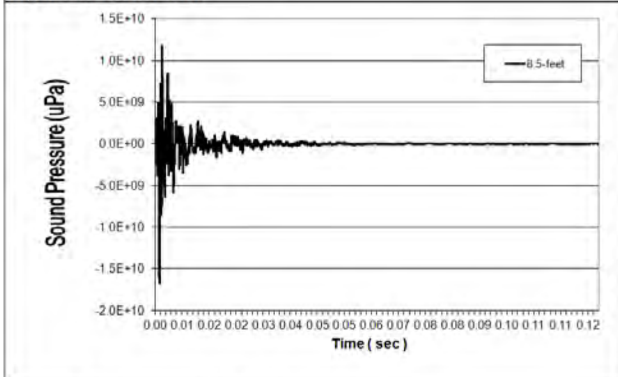


Figure b. Narrow Band Frequency Spectra

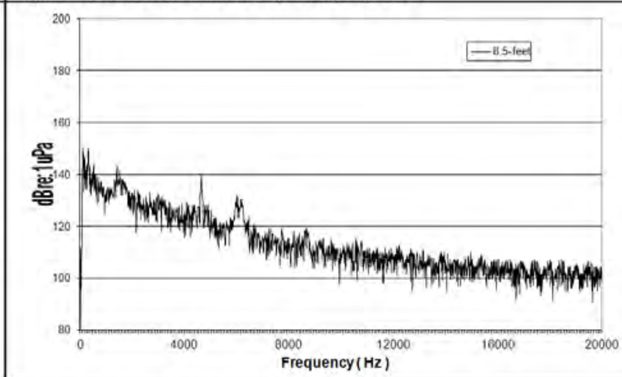


Figure c. Accumulation of Sound Energy

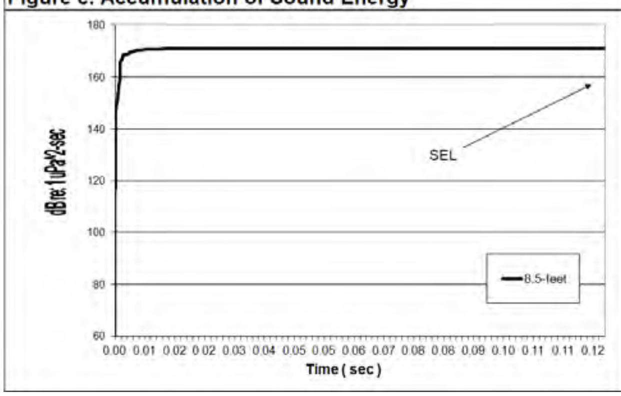


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 14:24	Peak	$RMS_{90\%}$*	SEL
8.5-feet	205	190	171

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

Figure 19: Waveform analysis of Pier 6 (75 Hz to 20 kHz).

Pier 6, 150 Hz to 20 kHz

Manette Bridge - Pier 6 - 150 Hz

Figure a. Waveform

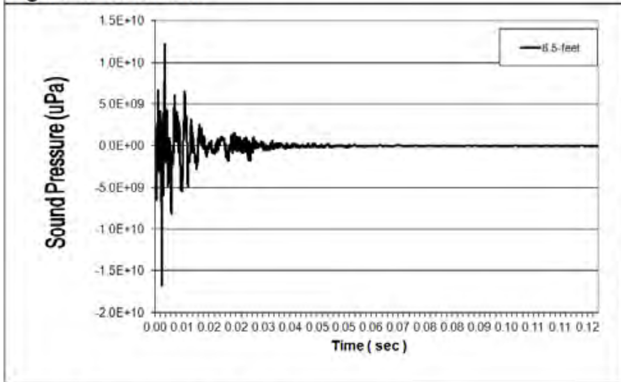


Figure b. Narrow Band Frequency Spectra

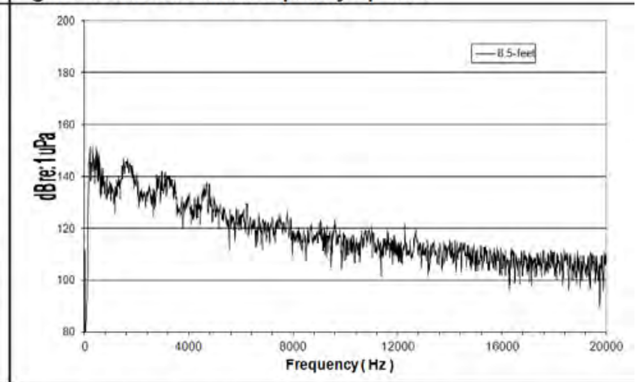


Figure c. Accumulation of Sound Energy

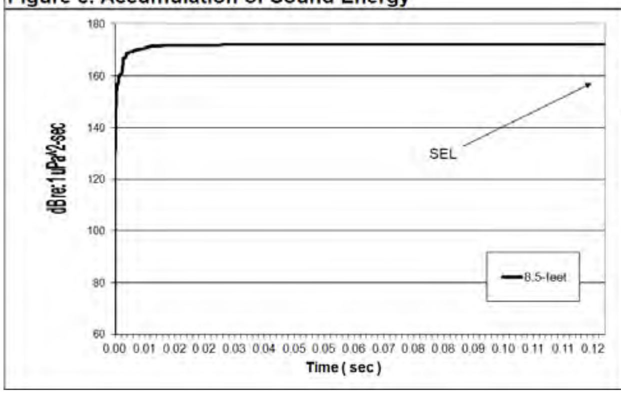


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 14:24	Peak	RMS90%*	SEL
8.5-feet	204	191	172

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

Figure 20: Waveform analysis of Pier 6 (150 Hz to 20 kHz).

Pier 6, 200 Hz to 20 kHz

Manette Bridge - Pier 6 - 200 Hz

Figure a. Waveform

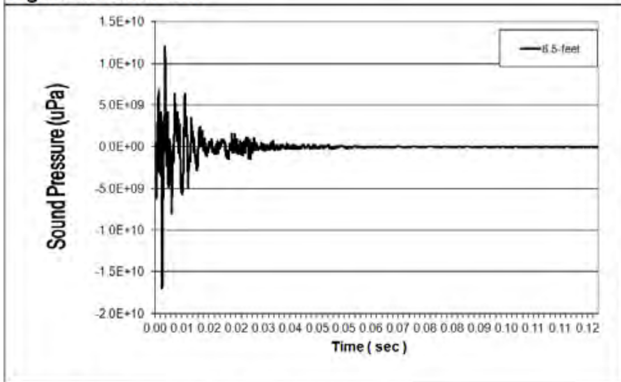


Figure b. Narrow Band Frequency Spectra

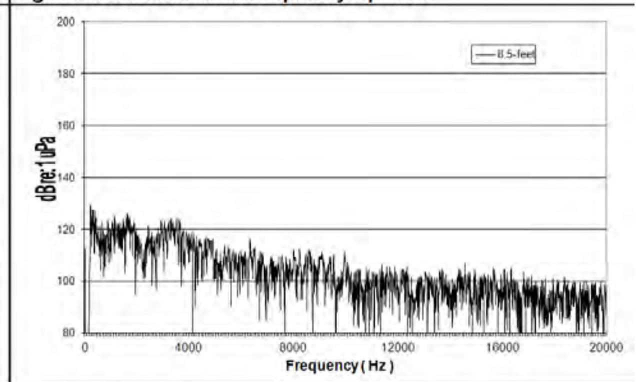


Figure c. Accumulation of Sound Energy

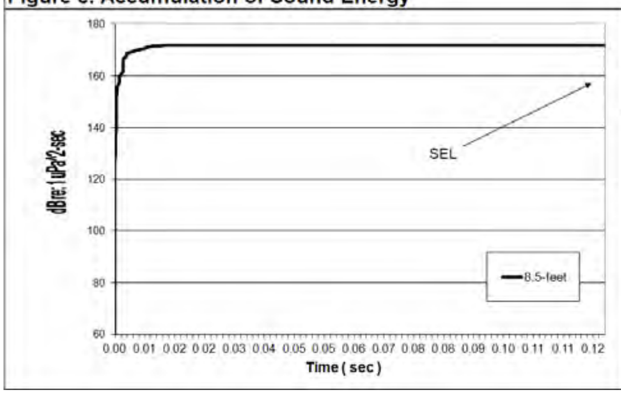


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 14:24	Peak	RMS90%*	SEL
8.5-feet	205	191	172

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

Figure 21: Waveform analysis of Pier 6 (200 Hz to 20 kHz).