UNDERWATER SOUND LEVELS ASSOCIATED WITH CONSTRUCTION OF THE SR 240 BRIDGE ON THE YAKIMA RIVER AT RICHLAND

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EXECUTIVE SUMMARY

This technical report describes the underwater sound levels associated with the pile driving activities for the construction of the westbound lanes of the SR 240 Bridge over the Yakima River (MP 36.25 to MP 36.84). Analysis of sound level impacts in the project area is based on the criteria set by the National Oceanic and Atmospheric Administration (NOAA) and existing knowledge available from literature.

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the instantaneous peak sound pressure level (SPL) and the Root Mean Square (RMS) pressure level during the impulse, which is sometimes referred to as the SPL or RMS level. The peak underwater pressure is the instantaneous maximum or minimum pressure observed during each pulse and can be presented as a pressure (e.g., μPa) or decibel (dB) referenced (re:) to the standard pressure of 1 μPa. The SPL or RMS level is the square root of the energy divided by the duration. This level, presented in dB re: 1 μPa, is equivalent to the mean square pressure level of the pulse. It has been used by NOAA Fisheries as criteria for judging impacts to marine mammals from underwater impulse-type sounds. The majority of literature uses peak sound pressure levels to evaluate injuries to fish. Except where otherwise noted, sound levels reported in this discussion are expressed in KiloPascals (kPa) and also converted to dB re: 1 μPa.

Underwater sound levels were several orders of magnitude lower than the limits of 75 kPa required by NOAA for this project (Table 1).

Table 1: Summary of Underwater Sound Level Impacts and Mitigation

		Sound Levels @ 30 ft. (kPa / dB)		Sound Levels @ 90 ft.[3] (kPa / dB)			
Pile	**Pile Wetted Length (Water Depth (ft.))**	**Mid Depth[1]**	**Bottom Depth[2]**	**Mid Depth**	**Bottom Depth**	**NOAA Limit (kPa / dB)**	**Mitigation Measures**
1	17	10.2 / 200	10.1 / 200	5.7 / 195	4.5 / 193	75 / 218	None
2	22	5.7 / 195	5.2 / 194	3.4 / 191	3.6 / 191	75 / 218	None
3	20	10.2 / 200	10.0 / 200	7.1 / 197	4.9 / 194	75 / 218	None
4	20	7.0 / 197	7.9 / 198	4.0 / 192	3.5 / 191	75 / 218	None
5	18	6.8 / 197	6.4 / 196	4.7 / 193	3.4 / 191	75 / 218	None

1 – For pile #1 = 8.5 ft., for pile #2 = 11 ft., for pile #3 = 10 ft., for pile #4 = 10 ft., & pile #5 = 9 ft.
2 – For pile #1 = 16 ft., for pile #2 = 21 ft., for pile #3 = 19 ft., for pile #4 = 19 ft., & for pile #5 = 17 ft.
3 – For pile #1 = 54 ft., for pile #2 = 38 ft., for pile #3 = 89 ft., for pile #4 = 81 ft., & for pile #5 = 74 ft.

INTRODUCTION

This technical report presents results of underwater sound levels measured during the driving of the five piles in the mid channel of the Yakima River during August 2004 (Contract number: C6522 in South Central Region). The driving of 16-inch diameter piles was conducted as part of the design for the replacement of the SR 240 Bridge on the south side of SR 240. Figure 1 is a vicinity map showing the general location of the pile driving activity.

PROJECT DESCRIPTION

This contract provides for the improvements of .59 miles of SR 240 in Benton County, with the replacement of the existing bridge with two new bridges and with the work necessary to tie the new bridges into the alignments east and west on the river crossing. This work consists of bridge demolition, construction of concrete pre-stressed girder bridges with approach slabs (including pile driving), earthwork, clearing and grubbing, removing asphalt concrete pavement, grading, surfacing, paving with asphalt concrete pavement, construction of temporary and permanent erosion control, concrete barrier placement, bicycle / pedestrian pathway construction, channelization, pavement markings, illumination, permanent signing, planting, construction of environmental mitigation areas and other work.

The second phase of work on this project described in this report is the construction of the westbound bridge on the north side of SR 240.

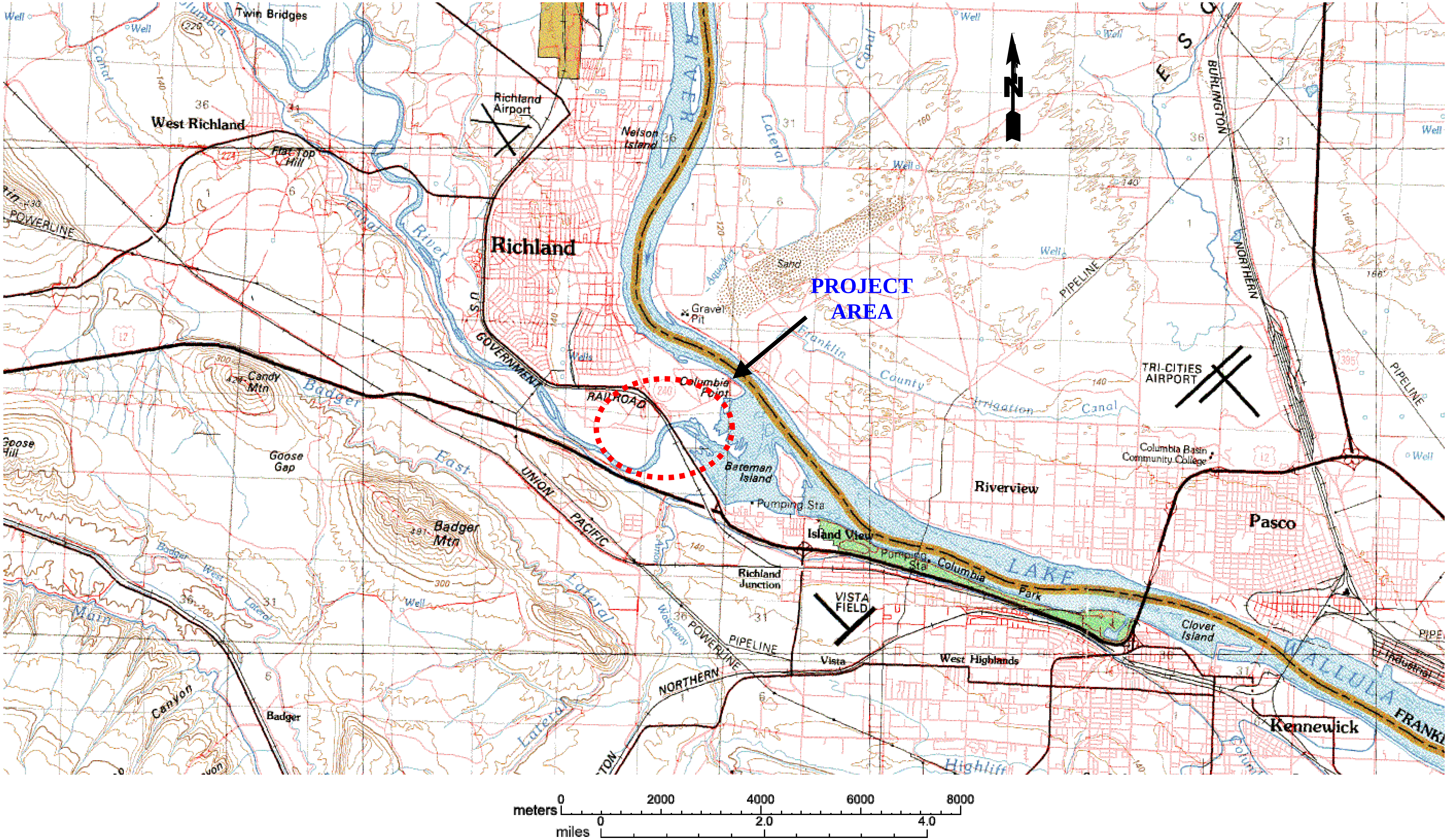


Figure 1: Vicinity Map

UNDERWATER SOUND LEVELS

CHARACTERISTICS OF UNDERWATER SOUND

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

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

For comparison, an underwater sound level of equal perceived loudness would be 62 dB higher to a comparable sound level in air.

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

Rise time is another descriptor used in wave form analysis to quantify the energy being generated. Rise time is the time in microseconds (ms) it takes the wave form to go from background levels to peak level.

Sound Exposure Level (SEL) frequently used for human exposures has recently been suggested as a possible metric to quantify impacts to fish (Hastings pers. comm..). SEL is calculated by squaring the energy values in micropascals collected during one impulse, typically where 95% of the energy occurs during the impulse. Then these values are cumulatively summed over the duration of the impulse. Finally the cumulative values are converted to dB and the last value to be summed is the SEL. The SEL values for selected impulses will be presented here for comparison.

METHODOLOGY

Underwater sound levels were measured using four Reson TC 4013 hydrophones, one at the bottom (approximately 1 foot above bottom) and one at mid-water level at distances of 30 and 90 feet from the piles. The measurement system includes a Brüel and Kjær Nexus type 2692 4-channel signal conditioner, which kept the high underwater sound levels from overloading the signal analyzer (Figure 2). The output of the Nexus signal conditioner was received by a Dactron Photon 4-channel signal spectrum analyzer that was attached to an Itronix GoBook II laptop computer. The waveform of the pile strikes along with the number of strikes, minimum, maximum, peak and RMS sound levels were captured and stored on the laptop hard drive for subsequent signal analysis. The system was calibrated in the field using a GRAS type 42AC high-level pistonphone hydrophone calibrator with a hydrophone adaptor. The calibration signal was 146 dB re: 1 μPa. The noise levels produced by the calibrator and measured by the measurement system were within 1 dB and considered acceptable. A photograph of the system and its components are shown in Figure 2.

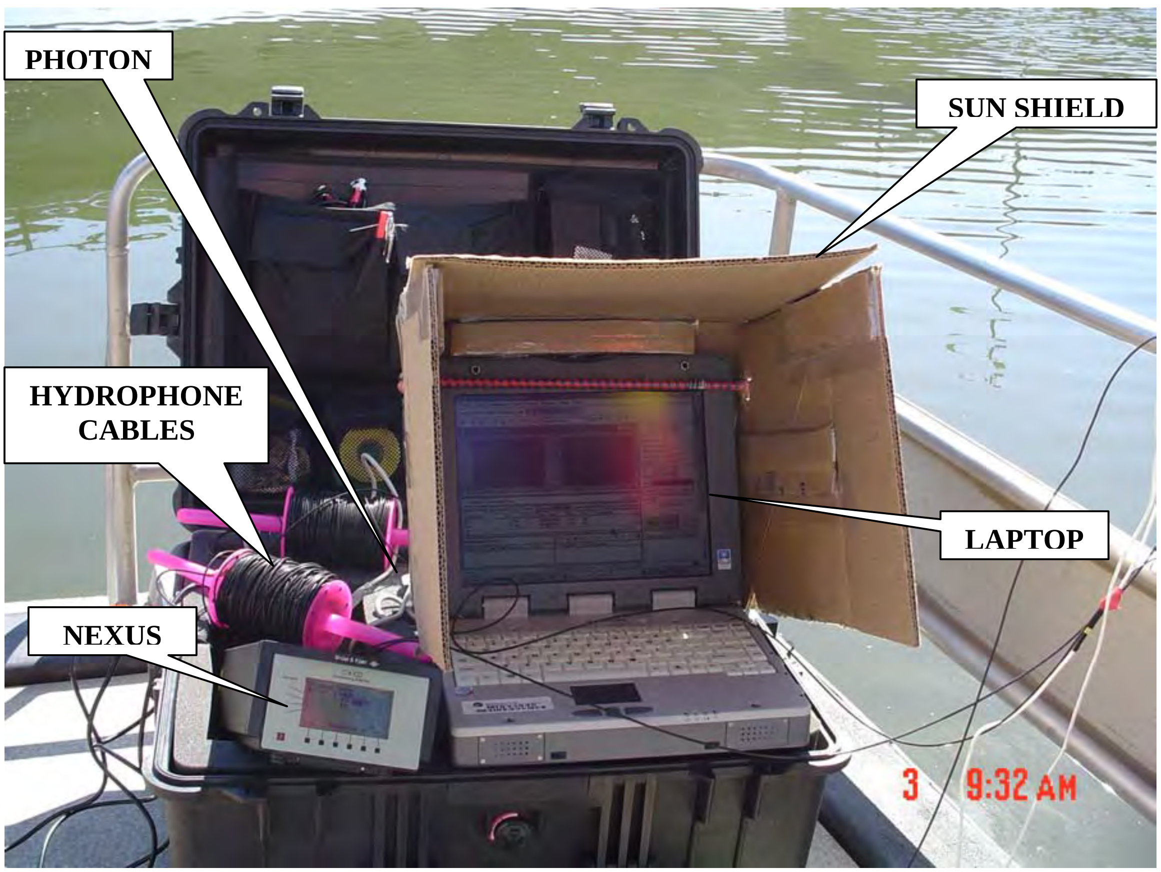


Figure 2: Underwater Sound Level Measurement Equipment

Signal analysis software provided with the Photon was set at a sampling rate of one sample every 41.7 μs (9,500 Hz). This is the highest sampling rate that the software allows with four input channels utilized at once. This sampling rate still gives sufficient resolution to catch the peaks and other relevant data.

The pile driver was an ICE Model 605 single-acting diesel pile hammer. It has a rated continuous energy of 81 kjoules with a maximum energy of 99 kjoules. Hammer weight is 13,900 lbs.

The substrate consisted of medium to very dense well to poorly graded gravel with sand, cobbles and boulders. The cobbles and boulders are nested in some areas. The soil is highly permeable and is generally found above elevation 310 to 320 feet. Below elevation 310 to 320 feet, dense to very dense non-plastic/low plasticity silt, sandy silt, and silty sand or poorly graded sand is present. Groundwater throughout the site is near the river level and follows the river level fluctuation.

Piles driven were open-ended hollow steel piles, 16 inches in diameter with a ½ inch wall thickness. Piles were driven to refusal in all cases.

Each measured pile site is described below:

1. Located on the east side of the existing SR 240 bridge approximately mid channel and approximately 135 feet from the shoreline in 17 feet of water (pile wetted length). Pile 1 was driven on the west side of the temporary work trestle.

2. Located on the east side of the existing SR 240 bridge approximately mid channel, 27 feet south of Pile 1, approximately 108 feet from the shoreline, and in 17 feet of water (pile wetted length). Pile 2 was driven on the west side of the work trestle.

3. Located on the east side of the existing SR 240 bridge, mid channel, approximately 189 feet from the shoreline, and in 18 feet of water (pile wetted length). Pile 3 was driven on the east side of the work trestle.

4. Located on the east side of the existing SR 240 bridge, mid channel, approximately 189 feet from the shoreline, and in 18 feet of water (pile wetted length). Pile 4 was driven on the west side of the work trestle.

5. Located on the east side of the existing SR 240 bridge, mid channel, approximately 187 feet from the shoreline, and in 18 feet of water (pile wetted length). Pile 5 was driven on the west side of the work trestle 2 feet shoreward of pile number 4.

Underwater sound level measurements were made by WSDOT for five piles driven in mid channel of the Yakima River on two separate days. On day 1, (August 5, 2004) underwater sound level measurements were made for the first two piles driven in water from a 12-foot aluminum boat. The first two hydrophones were attached to a weighted (5 lb.) nylon cord at 30 feet from the pile. The cord and hydrophone cables were attached to a surface float (Figure 3) and then to a series of surface floats between the 30 and 90 feet measurement locations. At the 90 foot location the cord was then weighted with a second weight and the second set of hydrophones attached to the nylon cord at bottom and mid water level. Due to miscalculations of appropriate line to deploy at the 90-foot distance measurements were made at 54 feet and 38 feet respectively for the first two piles.

On day 2, (August 9, 2004) underwater sound level measurements were made from a 12-foot aluminum boat. The configuration for deploying the floats was the same as the first day except greater care was taken for the final three piles to deploy the second set of hydrophones nearer the 90-foot distance. Figure 4 shows the measurement locations.

Water quality measurements were made prior to start of pile driving activities and during pile driving activities at a specified location down stream from the pile driving site to determine if there were any water quality impacts. Water quality parameters measured were water temperature, pH and turbidity.

Figure 3: Hydrophone Weight and Float System

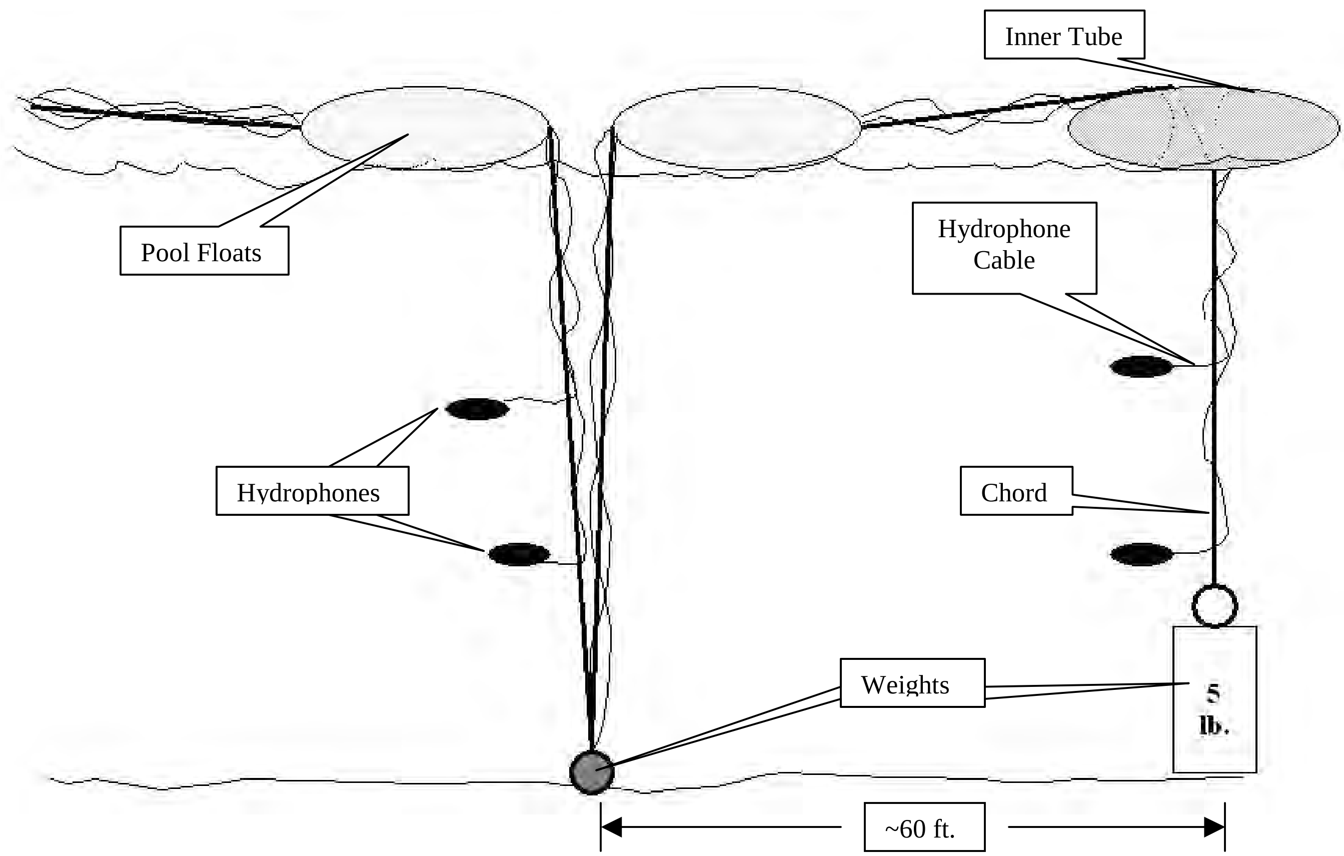
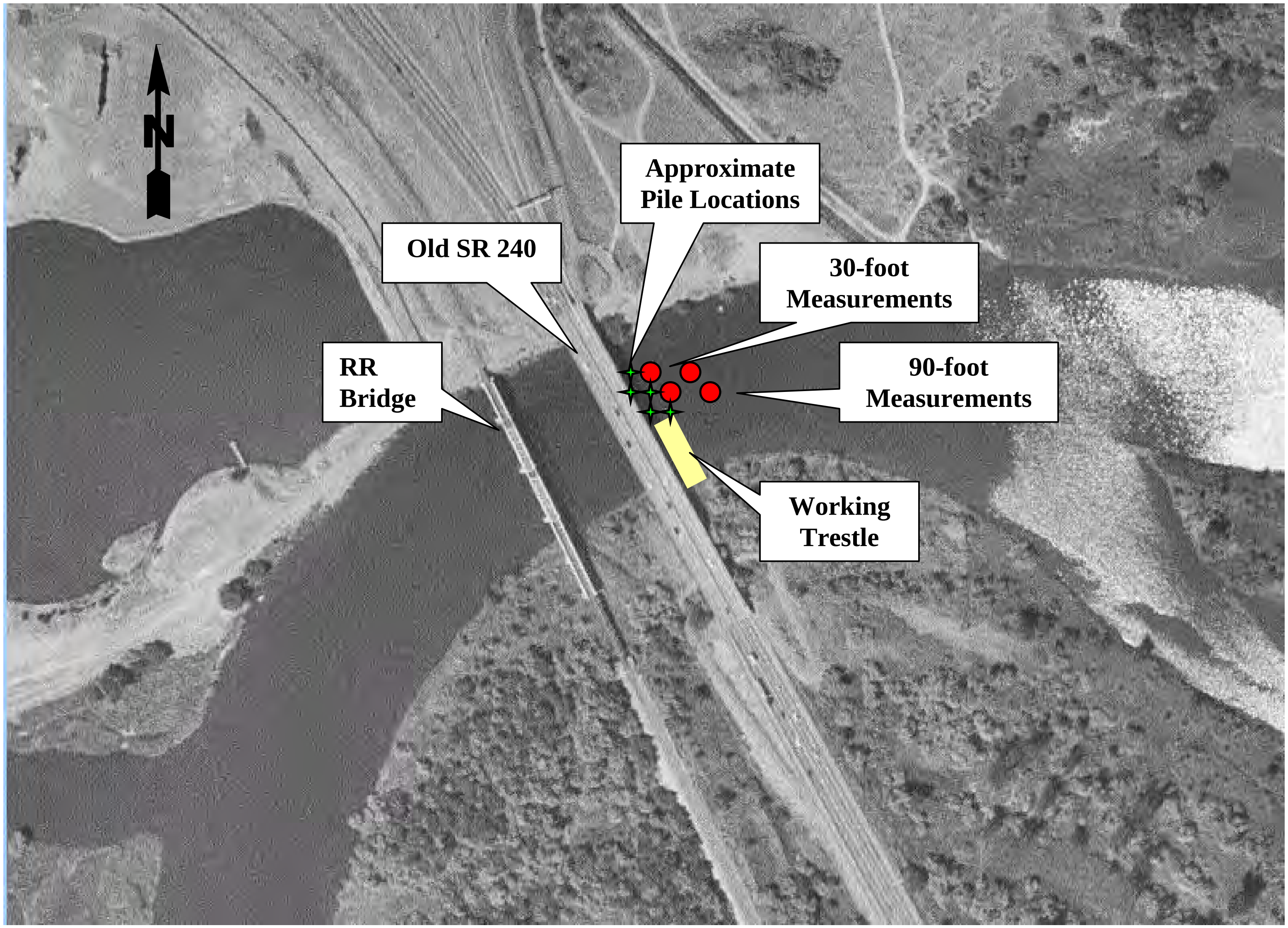


Figure 4: Sound Level Measurement Locations



RESULTS

UNDERWATER SOUND LEVELS

Measurements were made by WSDOT for unattenuated pile driving on 2 separate days. Peak background sound levels ranged from 0.005 to 0.052 kPa (114 dB to 159 dB). During pile driving events, WSDOT measured underwater peak sound pressure levels ranging from 3.4 kPa to 10.2 kPa (191 dB to 200 dB) (Table 2). Measurements were made near the bottom (approximately 1 foot above bottom) and at mid-water level.

Table 2: Summary of Noise Measurement Results

		Sound Levels @ 30 ft. (kPa / dB)		Sound Levels @ 90 ft.[3] (kPa / dB)			
Pile	**Pile Wetted Length (Water Depth (ft.))**	**Mid Depth[1]**	**Bottom Depth[2]**	**Mid Depth**	**Bottom Depth**	**NOAA Limit (kPa / dB)**	**Mitigation Measures**
1	17	10.2 / 200	10.1 / 200	5.7 / 195	4.5 / 193	75 / 218	None
2	22	5.7 / 195	5.2 / 194	3.4 / 191	3.6 / 191	75 / 218	None
3	20	10.2 / 200	10.0 / 200	7.1 / 197	4.9 / 194	75 / 218	None
4	20	7.0 / 197	7.9 / 198	4.0 / 192	3.5 / 191	75 / 218	None
5	18	6.8 / 197	6.4 / 196	4.7 / 193	3.4 / 191	75 / 218	None

1 – For pile #1 = 8.5 ft., for pile #2 = 11 ft., for pile #3 = 10 ft., for pile #4 = 10 ft., & pile #5 = 9 ft.
2 – For pile #1 = 16 ft., for pile #2 = 21 ft., for pile #3 = 19 ft., for pile #4 = 19 ft., & for pile #5 = 17 ft.
3 – For pile #1 = 54 ft., for pile #2 = 38 ft., for pile #3 = 89 ft., for pile #4 = 81 ft., & for pile #5 = 74 ft.

As can be seen in Figures 5 through 10 below the sound pressures, in Pascals (Pa) are highly variable from strike to strike. There is somewhat less variability in the measurements made at 30 feet distance from the pile than at 90 feet. This variability is most likely due to several factors such differences in substrate as the pile is driven, adjustments of the hammer energy, and angle of the hammer striking the pile.

Figure 5: Time Traces of Pile 1 in Pascals for Hydrophones at 30 Feet (Blue and Green) and at 54 feet (Red and Purple), One Foot from Bottom and Mid Water Depth (y-scale approximate).

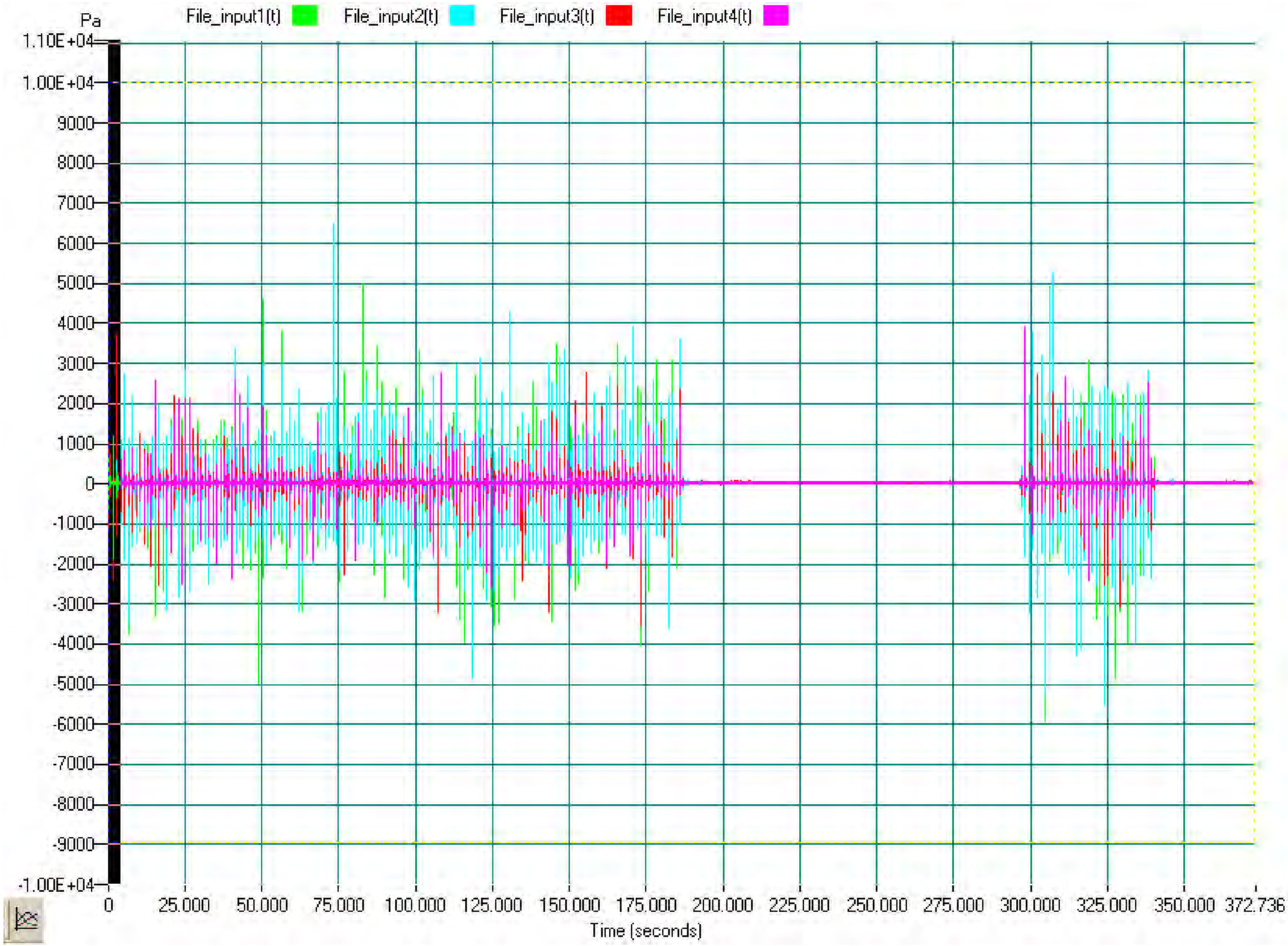


Figure 6: Time Traces of Pile 2 in Pascals for Hydrophones at 30 Feet (Blue and Green) and at 38 Feet (Red and Purple), One Foot from Bottom and Mid Water Depth (y-scale approximate).

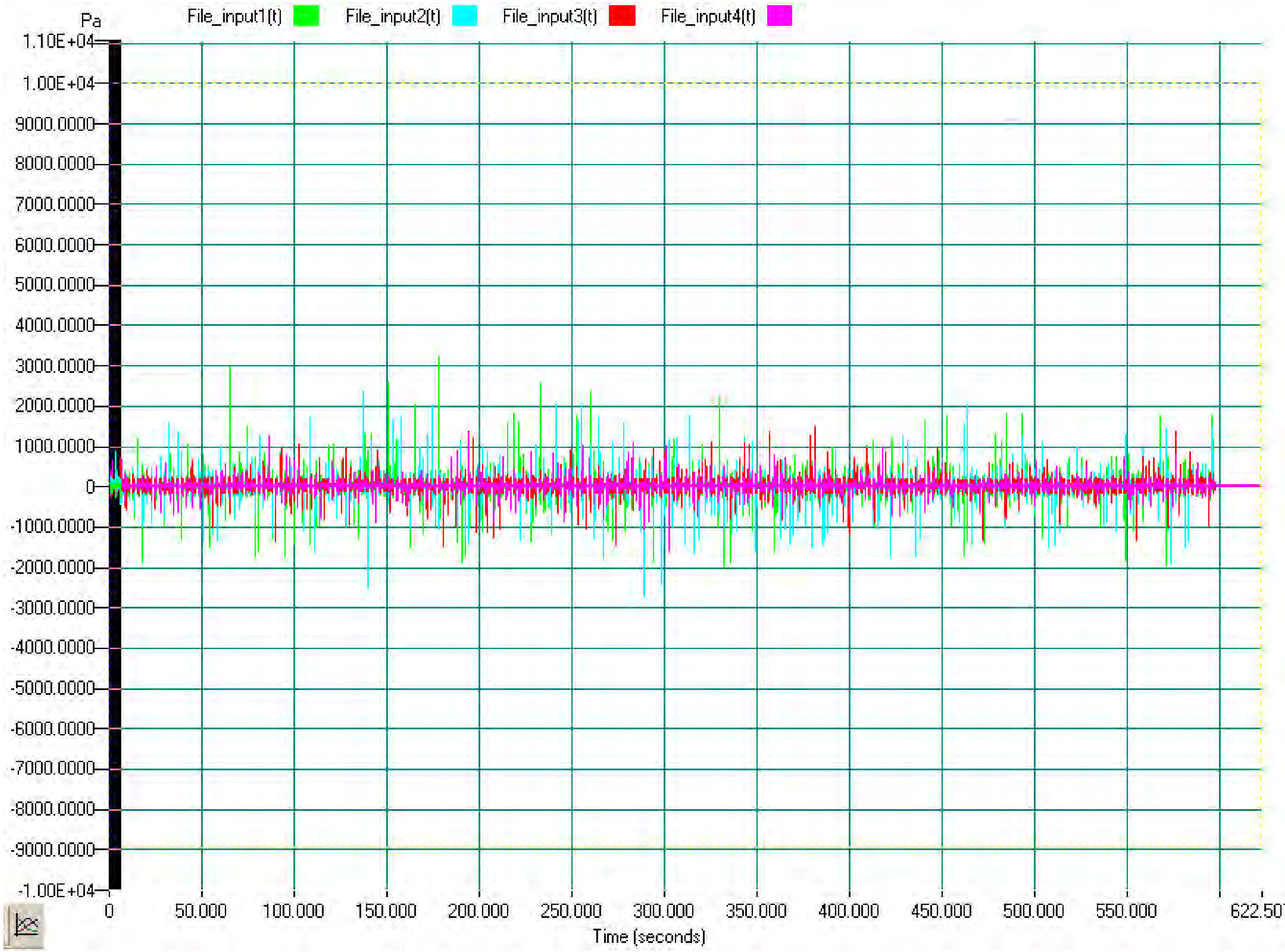


Figure 7: Time Traces of Pile 3 (first phase) in Pascals for Hydrophones at 30 Feet (Blue and Green) and at 89 Feet (Red and Purple), One Foot from Bottom and Mid Water Depth (y-scale approximate).

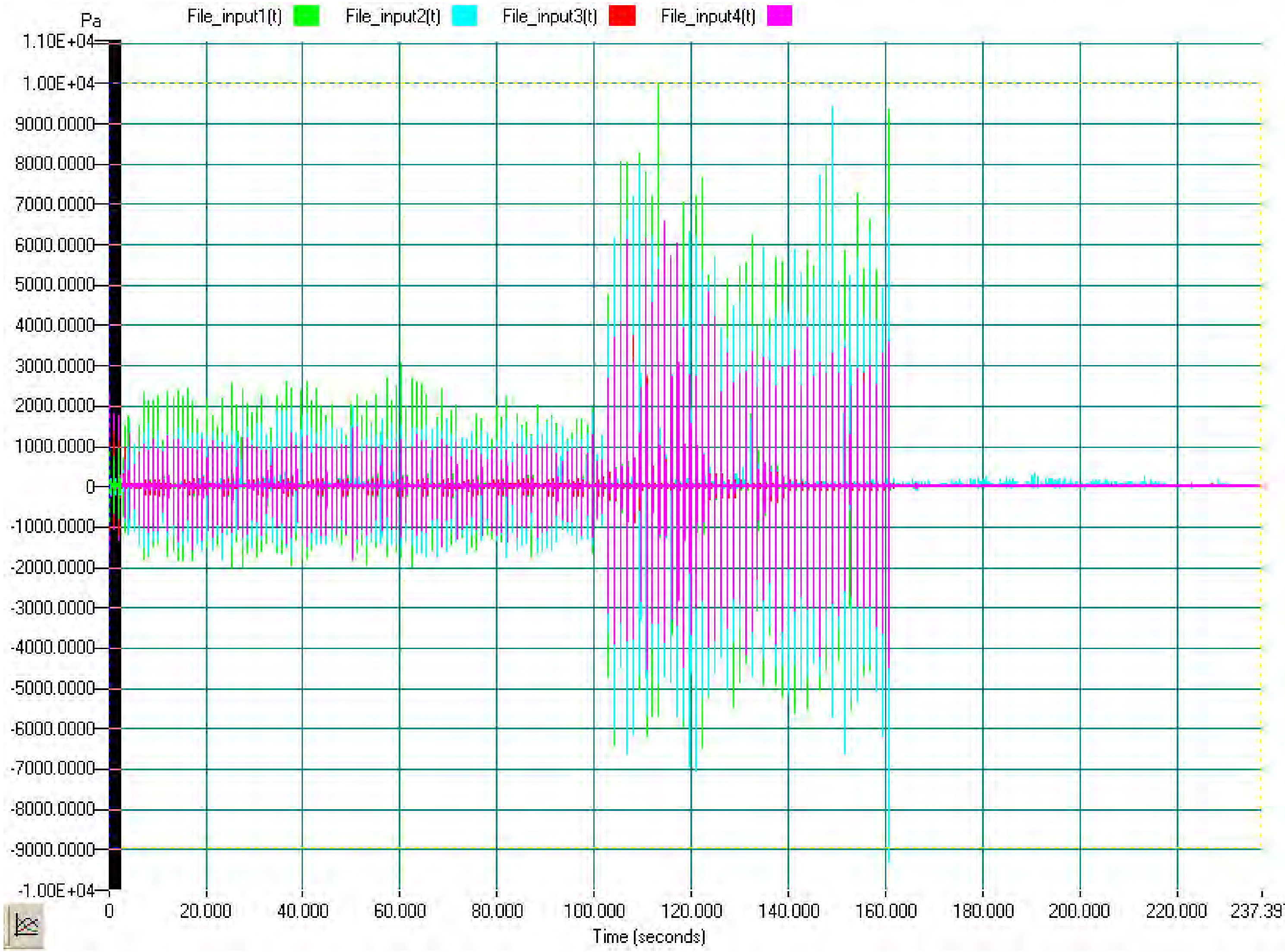


Figure 8: Time Traces of Pile 3 (Second Phase) in Pascals for Hydrophones at 30 Feet (Blue and Green) and at 89 Feet (Red and Purple), One Foot from Bottom and Mid Water Depth (y-scale approximate).

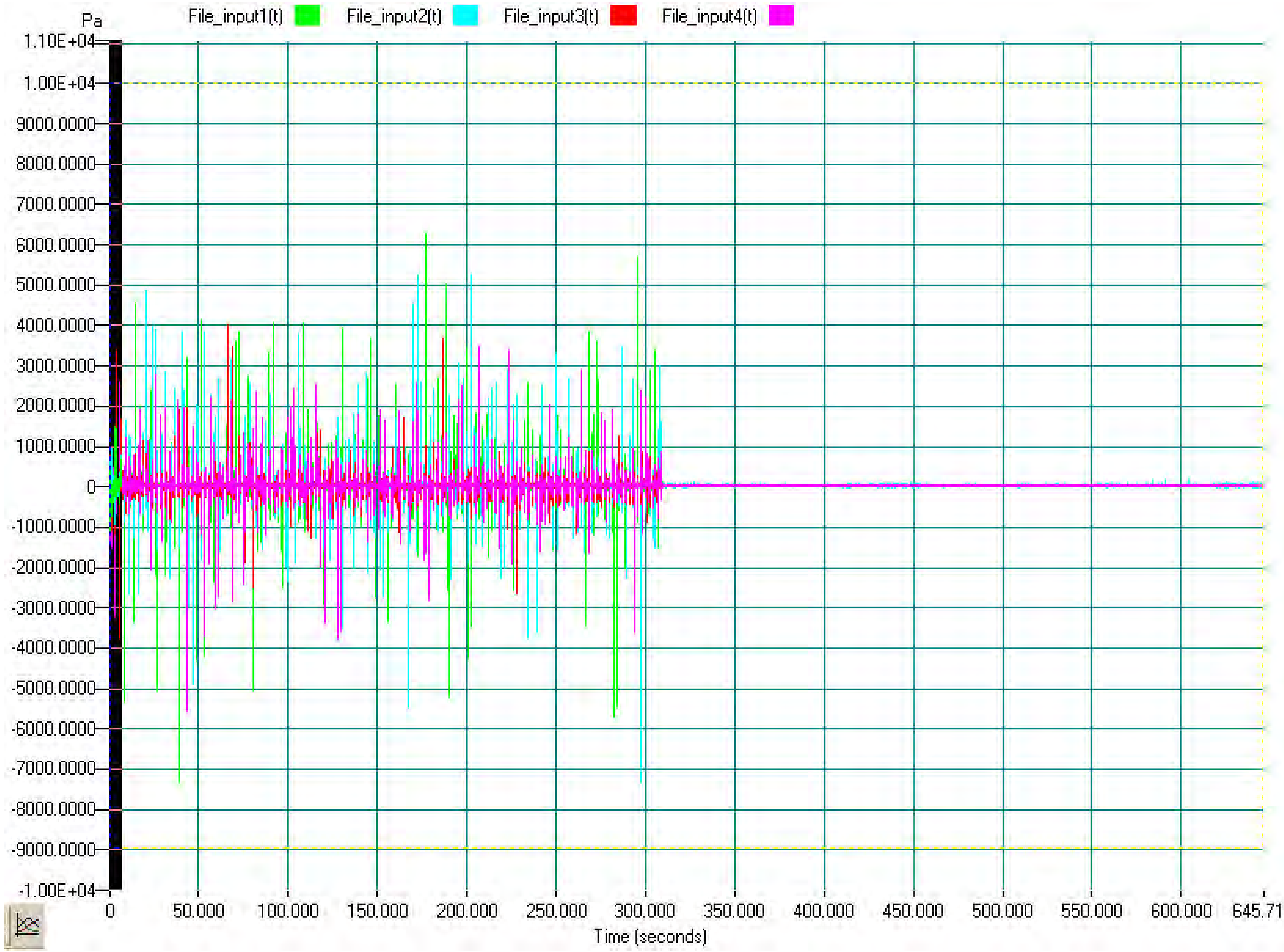


Figure 9: Time Traces of Pile 4 in Pascals for Hydrophones at 30 Feet (Blue and Green) and 81 Feet (Red and Purple), One Foot from Bottom and Mid Water Depth (y-scale approximate).

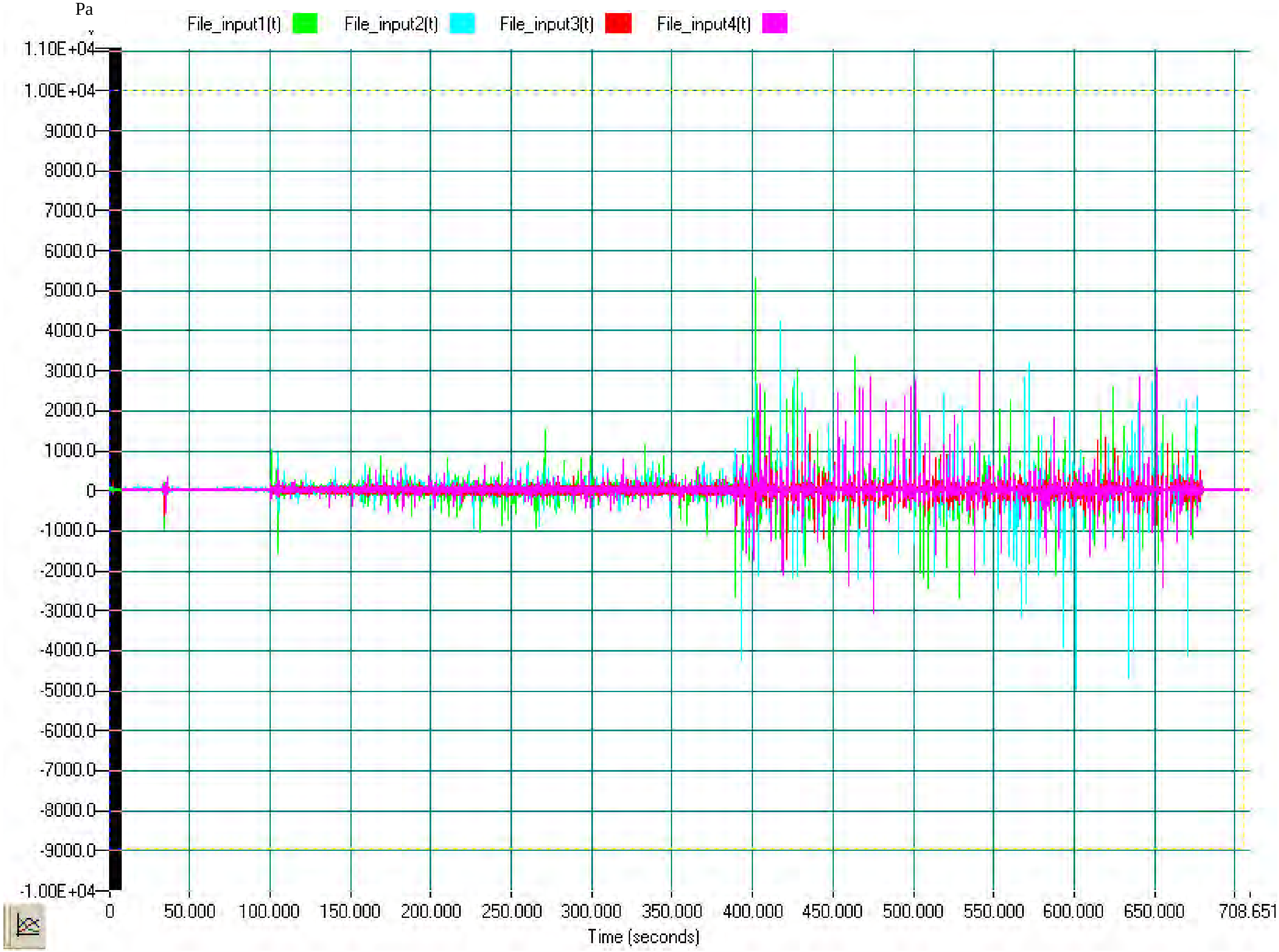
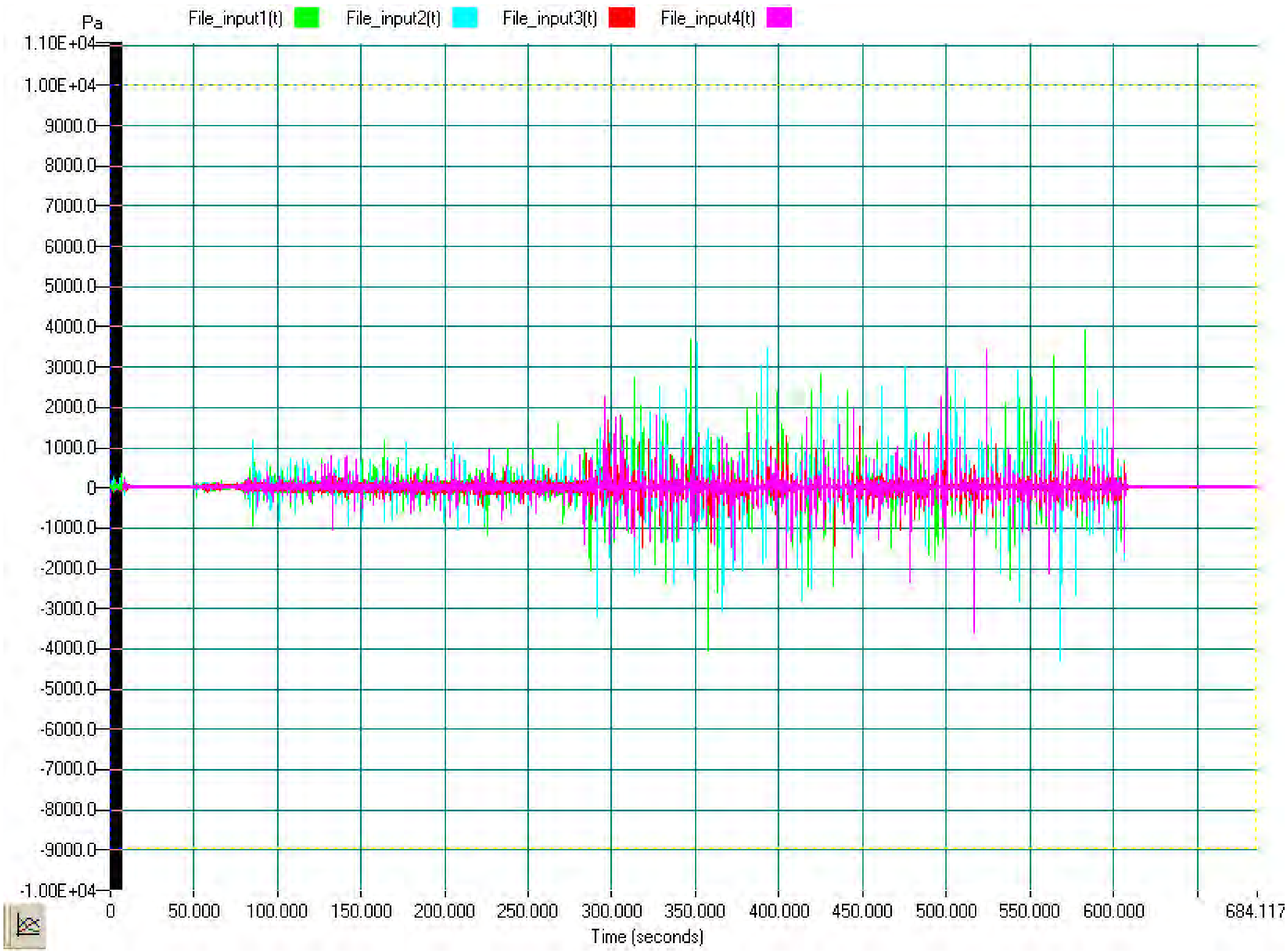


Figure 10: Time Traces of Pile 5 in Pascals for Hydrophones at 30 Feet (Blue and Green) and 74 Feet (Red and Purple), One Foot from Bottom and Mid Water Depth (y-scale approximate).



Pile 1

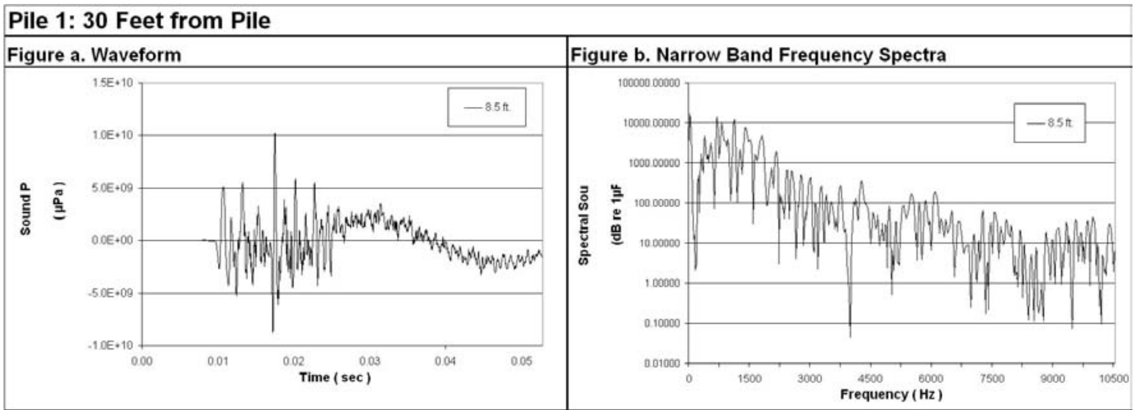
Measurements were made at 30 and 54 feet from the pile at 8.5 feet depth and one foot from the bottom. Due to a miscalculation in placing the hydrophones 90 feet from the pile the actual distance was calculated from the difference in sound arrival times between the 30 foot and second pair of hydrophones to be located only 54 feet from the pile. The first 15-20 seconds of the pile driving event were not recorded because the hydrophones were not deployed quickly enough.

Measurements made 30-feet from the pile at 8.5 feet depth had a peak value of 10.2 kPa (200 dB), RMS value was 187, and Sound Exposure Level (SEL) was 173 (Figure 11, a-d). One foot from the bottom the peak level was 10.1 kPa (200 dB), RMS value was 186 dB and the SEL value was 174 dB (Figure 12, a-d).

Measurements made 54-feet from the pile at 8.5-feet had a peak value of 5.7 kPa (195 dB), RMS value was 183, and Sound Exposure Level (SEL) was 168 (Figure 13, a-d). One foot from the bottom the peak level was 4.5 kPa (193 dB), RMS value was 183 dB and the SEL value was 167 dB (Figure 14, a-d).

In Figures 11b-14b below the acoustical frequency content of underwater impulses indicates that the dominant energy in each pile strike is between about 50 and 4000 Hz with most energy contained over the range of 0 to 1600 Hz.

Figure 11: Waveform Analysis for Pile Number 1, 8.5-Feet Deep, 30-Feet from Pile.



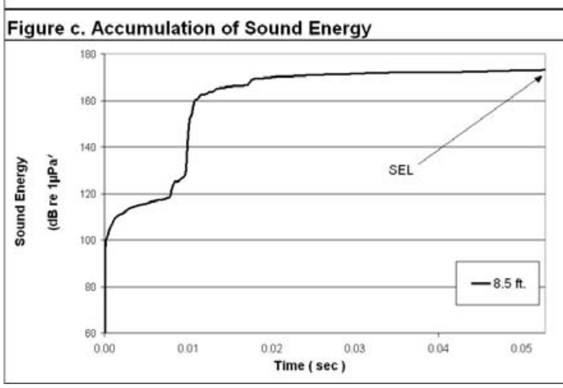


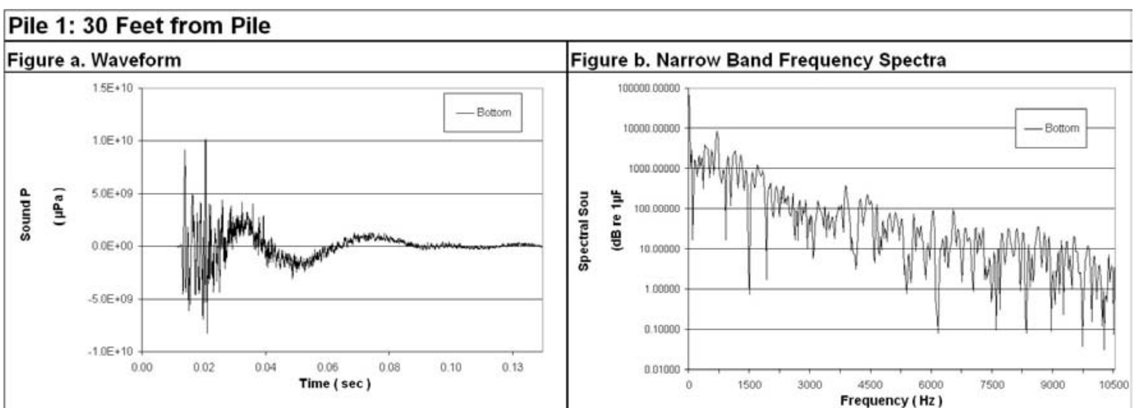
Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

8.5-ft - 10:20:00	Peak	RMS90%*	SEL
8.5 ft.	200	187	173

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

Figure 12: Waveform Analysis for Pile Number 1, 1-Foot from Bottom, 30-Feet from Pile.



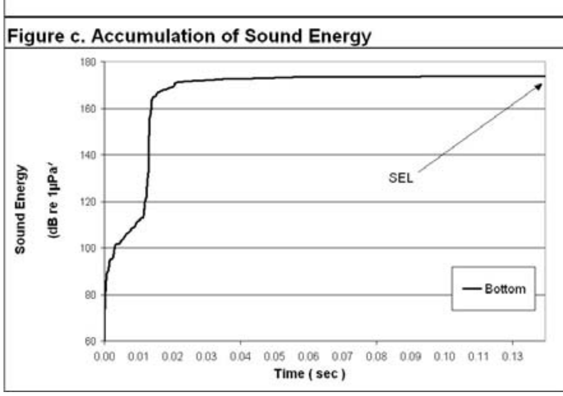


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Bottom - 10:20:00	Peak	RMS90%*	SEL
Bottom	200	186	174

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

Figure 13: Waveform Analysis for Pile Number 1, 8.5-Feet Deep, 54-Feet from Pile.

Pile 1: 54 Feet from Pile

Figure a. Waveform

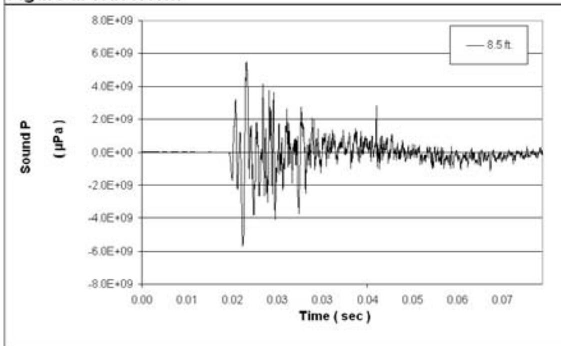


Figure b. Narrow Band Frequency Spectra

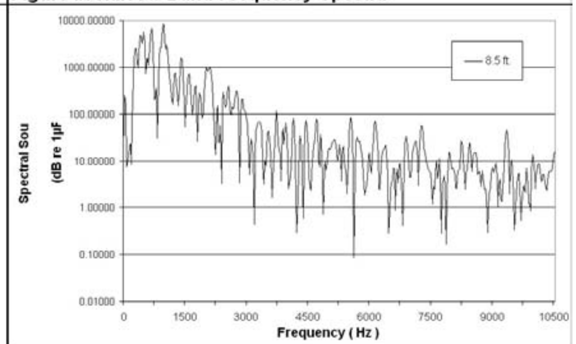


Figure c. Accumulation of Sound Energy

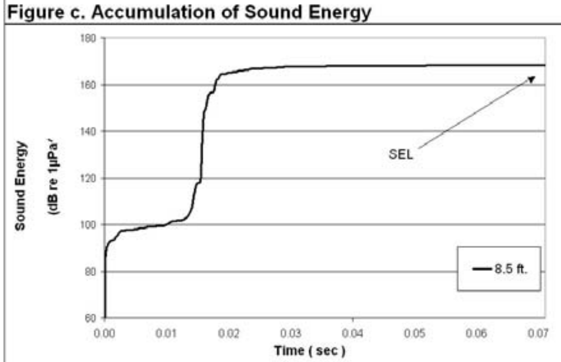


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

54-feet - 10:20:00	Peak	RMS90%*	SEL
8.5 ft.	195	183	168

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

Figure 14: Waveform Analysis for Pile Number 1, Bottom, 54-Feet from Pile.

Pile 1: 54 Feet from Pile

Figure a. Waveform

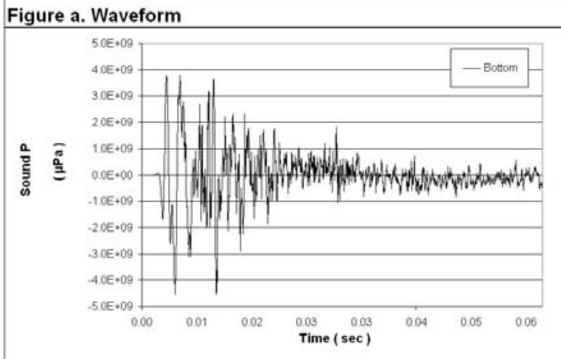


Figure b. Narrow Band Frequency Spectra

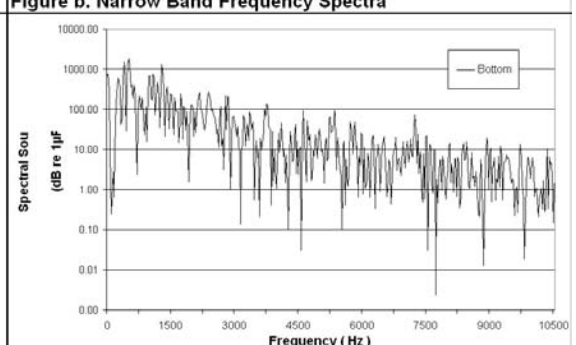


Figure c. Accumulation of Sound Energy

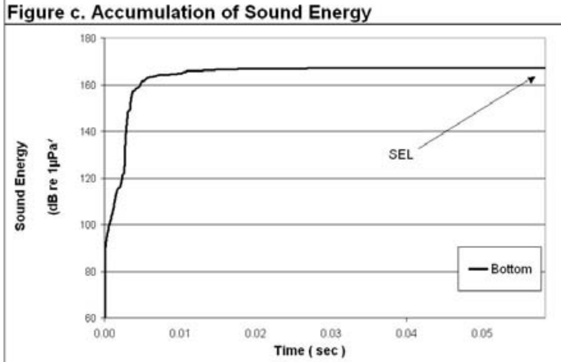


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

54-feet - 10:20:00	Peak	RMS90%*	SEL
Bottom	193	183	167

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

Examination of the waveforms for pile number 1 indicate a rise time of 2 milliseconds (msec). A moderately rapid fluctuation in underpressure to over pressure occurs within about 0.6 msec. The decay time of the impulse is relatively slow, lasting about 50 msec. Much of the energy associated with the impulse occurs within the first 20 msec.

There was a 4.5 kPa (11.5 dB) difference between the bottom and mid level measurements with the highest value measured at mid level.

Pile 2

Measurements were made at 30 and 38 feet from the pile at 11 feet depth and one foot from the bottom. Due to a miscalculation in placing the second set of hydrophones 90 feet from the pile the actual distance was calculated from the difference in sound arrival times between the 30 foot and second set of hydrophones. The distance was found to be only 38 feet from the pile instead of 90. The first 15-20 seconds of the pile driving event were not recorded because the hydrophones were not deployed quickly enough.

Measurements made 30-feet from the pile at 11 feet depth had a peak value of 5.7 kPa (195 dB), RMS value was 181, and Sound Exposure Level (SEL) was 164 (Figure 15, a-d). One foot from the bottom the peak level was 5.2 kPa (194 dB), RMS value was 177 dB and the SEL value was 162 dB (Figure 16, a-d).

Measurements made 38-feet from the pile at 11-feet depth the peak value was 3.4 kPa (191 dB), RMS value was 173, and Sound Exposure Level (SEL) was 157 (Figure 17, a-d). One foot from the bottom the peak level was 3.6 kPa (191 dB), RMS value was 170 dB and the SEL value was 160 dB (Figure 18, a-d).

In Figures 15b-18b below the acoustical frequency content of underwater impulses indicates that the dominant energy in each pile strike is between about 50 and 4000 Hz with most energy contained over the range of 0 to 1600 Hz.

Figure 15: Waveform Analysis for Pile Number 2, 11 Feet Deep, 30-Feet from Pile.

Pile 2: 30 Feet from Pile

Figure a. Waveform

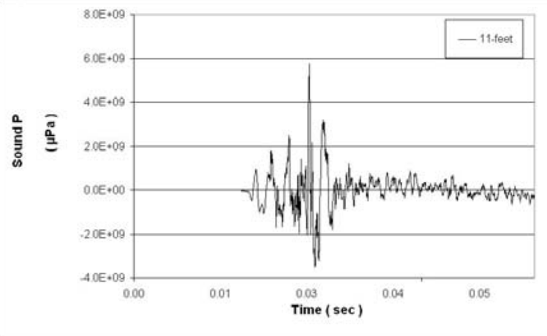


Figure b. Narrow Band Frequency Spectra

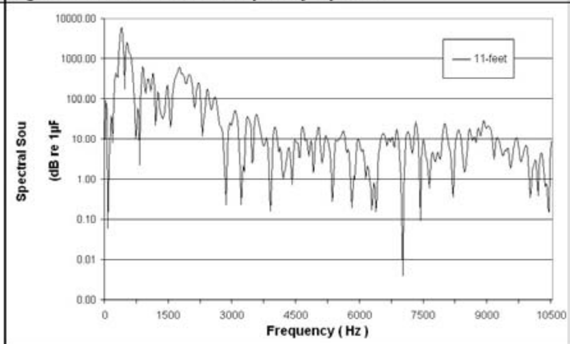


Figure c. Accumulation of Sound Energy

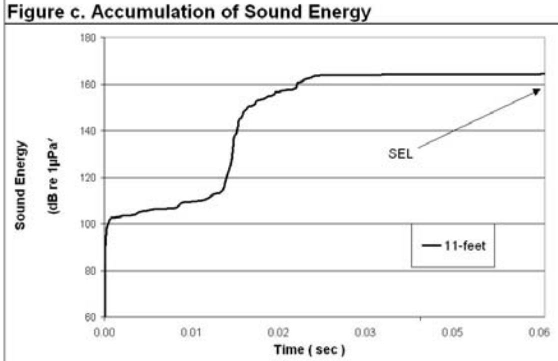


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

30-feet - 11:10:00	Peak	RMS90%*	SEL
11-feet	195	181	164

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

Figure 16: Waveform Analysis for Pile Number 2, 1-Foot from Bottom, 30-Feet from Pile.

Pile 2: 30 Feet from Pile

Figure a. Waveform

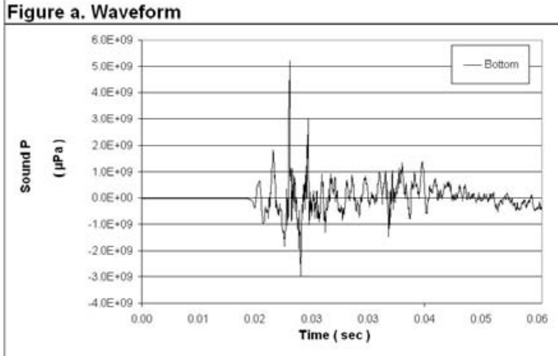


Figure b. Narrow Band Frequency Spectra

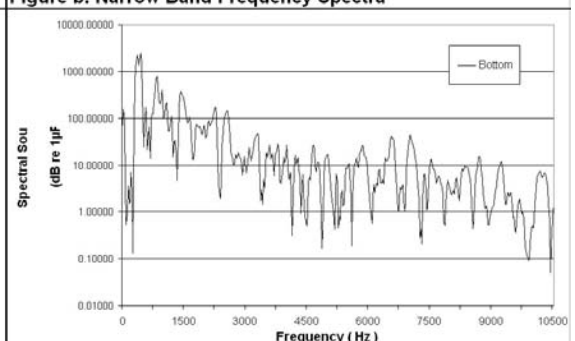


Figure c. Accumulation of Sound Energy

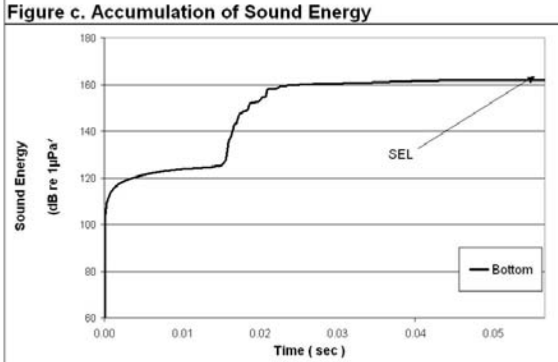


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

30-feet - 11:10:00	Peak	RMS90%*	SEL
Bottom	194	177	162

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

Figure 17: Waveform Analysis of Pile Number 2, 8.5-Feet Deep, 54-Feet from Pile.

Pile 2: 38 Feet from Pile

Figure a. Waveform

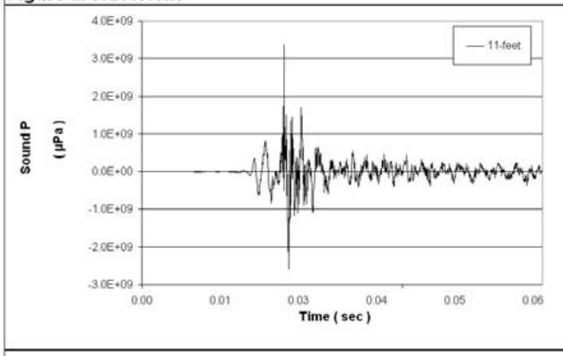


Figure b. Narrow Band Frequency Spectra

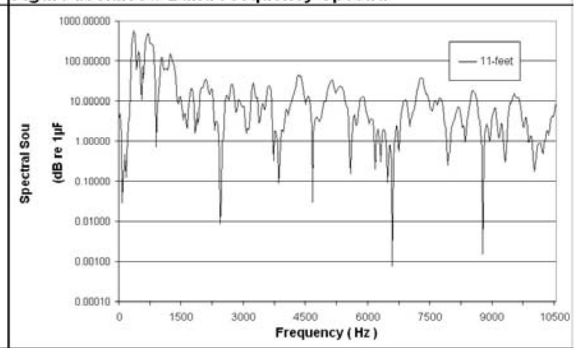


Figure c. Accumulation of Sound Energy

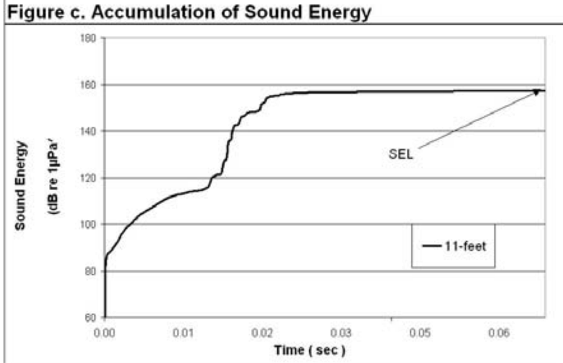


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

38-feet - 11:10:00	Peak	RMS90%*	SEL
11-feet	191	173	157

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

Figure 18: Waveform Analysis of Pile Number 2, Bottom, 54-Feet from Pile.

Pile 2: 38 Feet from Pile

Figure a. Waveform

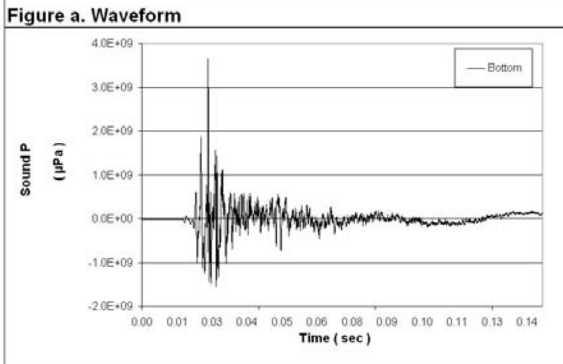


Figure b. Narrow Band Frequency Spectra

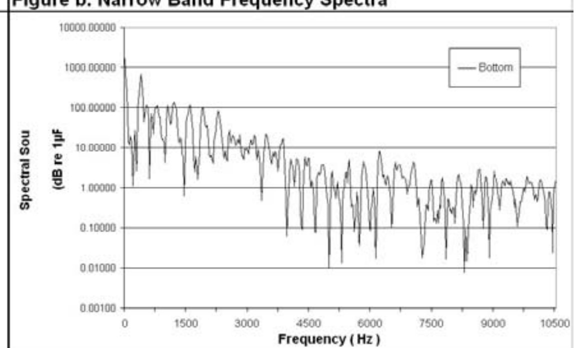


Figure c. Accumulation of Sound Energy

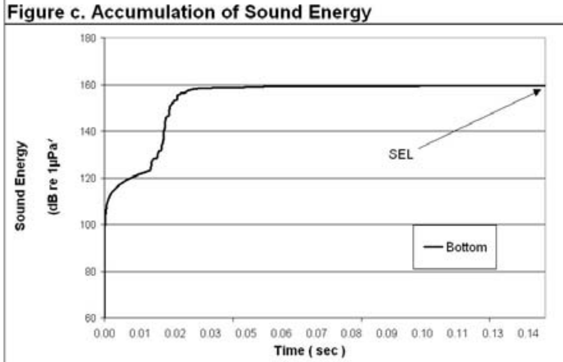


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

38-feet - 11:10:00	Peak	RMS90%*	SEL
Bottom	191	170	160

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

Examination of the waveforms for pile number 2 indicate a rise time of 8 milliseconds (msec). A moderately rapid fluctuation in underpressure to over pressure occurs within about 2 msec. The decay time of the impulse is relatively slow, lasting about 50 msec. Much of the energy associated with the impulse occurs within the first 20 msec.

There was a 4.5 kPa (11.5 dB) difference between the bottom and mid level measurements with the highest value measured at mid level.

Pile 3

Measurements were made at 30 and 89 feet from the pile at 10 feet depth and one foot from the bottom. As can be seen in Figure 7 the contractor drove pile number 3 with reduced force for just under two minutes and then increased energy to the pile driver. It appeared the contractor had finished driving and so the recording was stopped. The contractor then started driving again for another 5.5 minutes (Figure 8). The highest peak values recorded were during the second phase of the driving of pile number 3.

The peak value at 10 feet deep was 10.2 kPa (200 dB), RMS value was 186, and Sound Exposure Level (SEL) was 170 (Figure 19, a-d). One foot from the bottom the peak level was 10.0 kPa (200 dB), RMS value was 186 dB and the SEL value was 171 dB (Figure 20, a-d).

Measurements made 89-feet from the pile at 10-feet depth had a peak value of 7.1 kPa (197 dB), RMS value was 182, and Sound Exposure Level (SEL) was 167 (Figure 21, a-d). One foot from the bottom the peak level was 4.9 kPa (194 dB), RMS value was 177 dB and the SEL value was 164 dB (Figure 22, a-d).

In Figures 19b-22b below the acoustical frequency content of underwater impulses indicates that the dominant energy in each pile strike is between about 50 and 4000 Hz with most energy contained over the range of 0 to 1600 Hz.

Figure 19: Waveform Analysis for Pile Number 3, 10 Feet Deep, 30-Feet from Pile.

Pile 3: 30 Feet from Pile

Figure a. Waveform

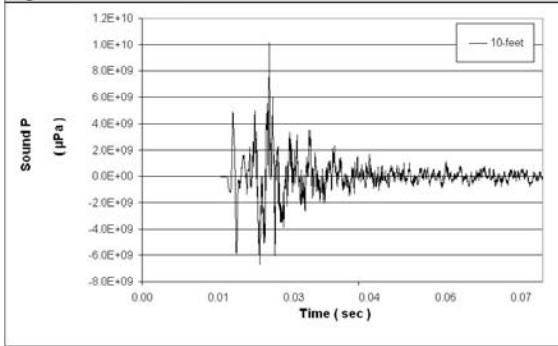


Figure b. Narrow Band Frequency Spectra

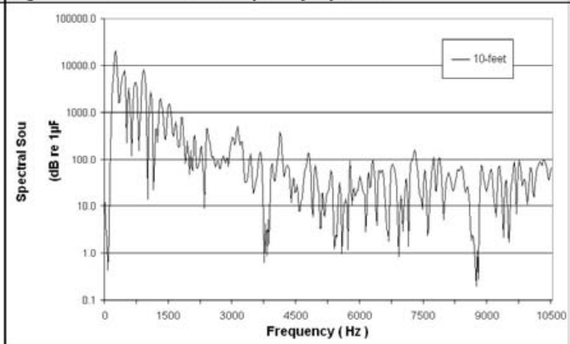


Figure c. Accumulation of Sound Energy

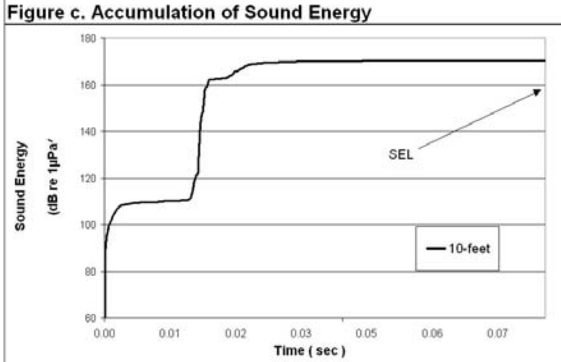


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

30-feet - 08:20:00	Peak	RMS90%*	SEL
10-feet	200	186	170

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

Figure 20: Waveform Analysis for Pile Number 3, 1-Foot from Bottom, 30-Feet from Pile.

Pile 3: 30 Feet from Pile

Figure a. Waveform

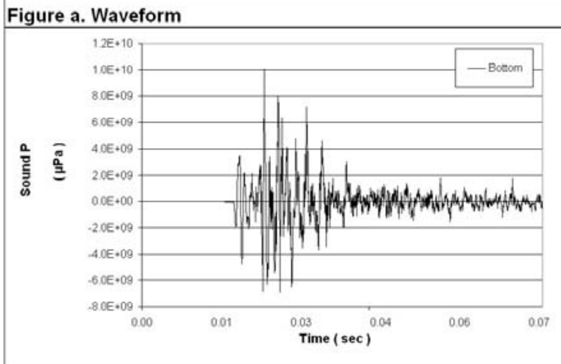


Figure b. Narrow Band Frequency Spectra

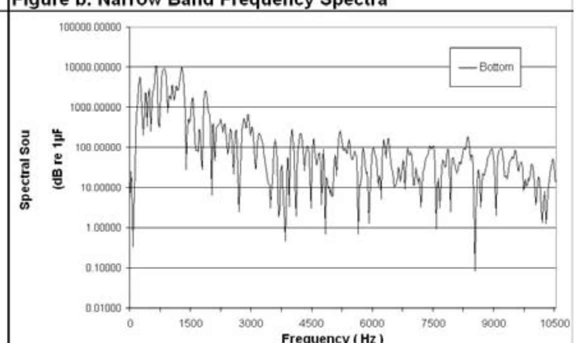


Figure c. Accumulation of Sound Energy

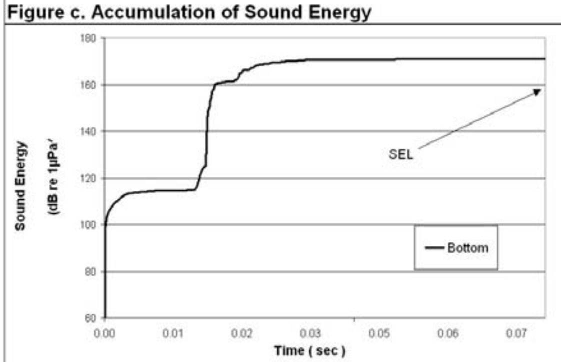


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

30-feet - 08:20:00	Peak	RMS90%*	SEL
Bottom	200	186	171

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

Figure 21: Waveform Analysis of Pile Number 3, 10-Feet Deep, 89-Feet from Pile.

Pile 3: 89 Feet from Pile

Figure a. Waveform

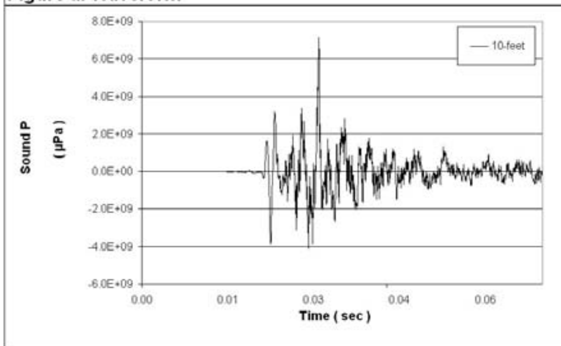


Figure b. Narrow Band Frequency Spectra

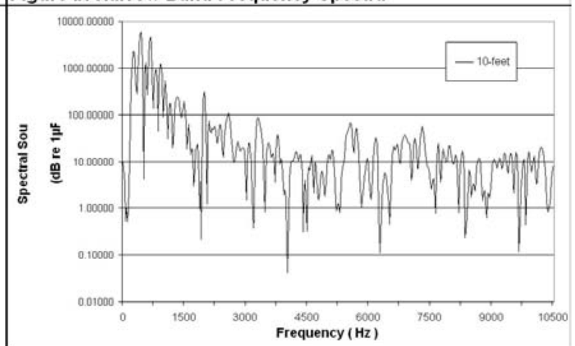


Figure c. Accumulation of Sound Energy

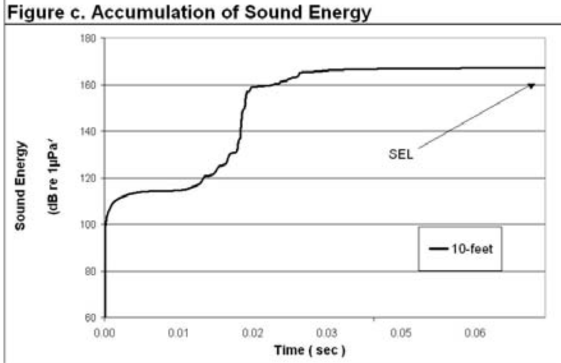


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

89-feet - 08:20:00	Peak	RMS90%*	SEL
10-feet	197	182	167

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

Figure 22: Waveform Analysis of Pile Number 3, Bottom, 89-Feet from Pile.

Pile 3: 89 Feet from Pile

Figure a. Waveform

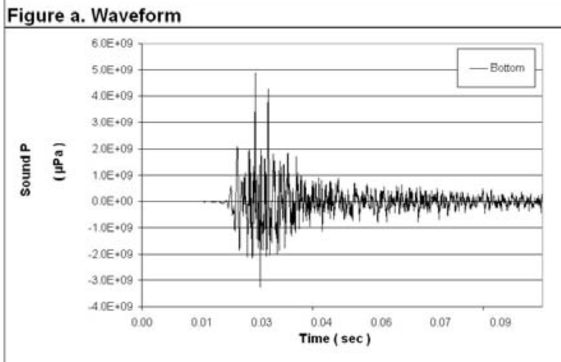


Figure b. Narrow Band Frequency Spectra

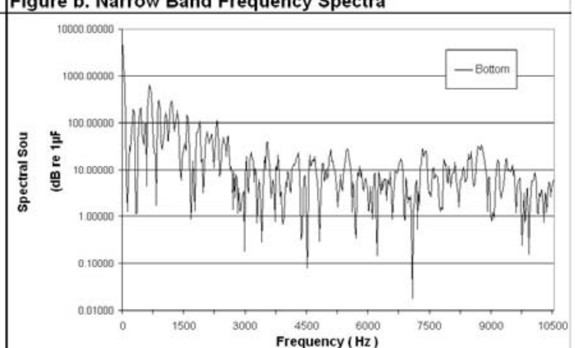


Figure c. Accumulation of Sound Energy

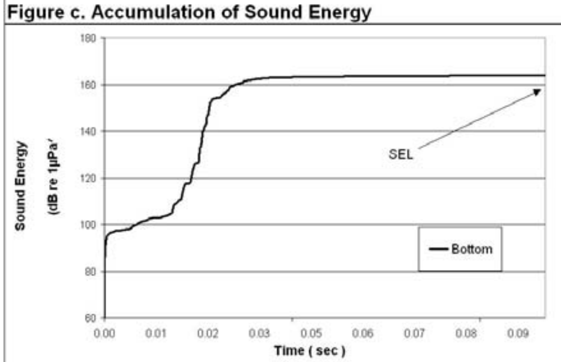


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

89-feet - 08:20:00	Peak	RMS90%*	SEL
Bottom	194	177	164

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

Examination of the waveforms for pile number 3 indicate a rise time of 2 milliseconds (msec). A moderately rapid fluctuation in underpressure to over pressure occurs within about 0.5 msec. The decay time of the impulse is relatively slow, lasting about 50 msec. Much of the energy associated with the impulse occurs within the first 26 msec.

There was a 4.5 kPa (11.5 dB) difference between the bottom and mid level measurements with the highest value measured at mid level.

Pile 4

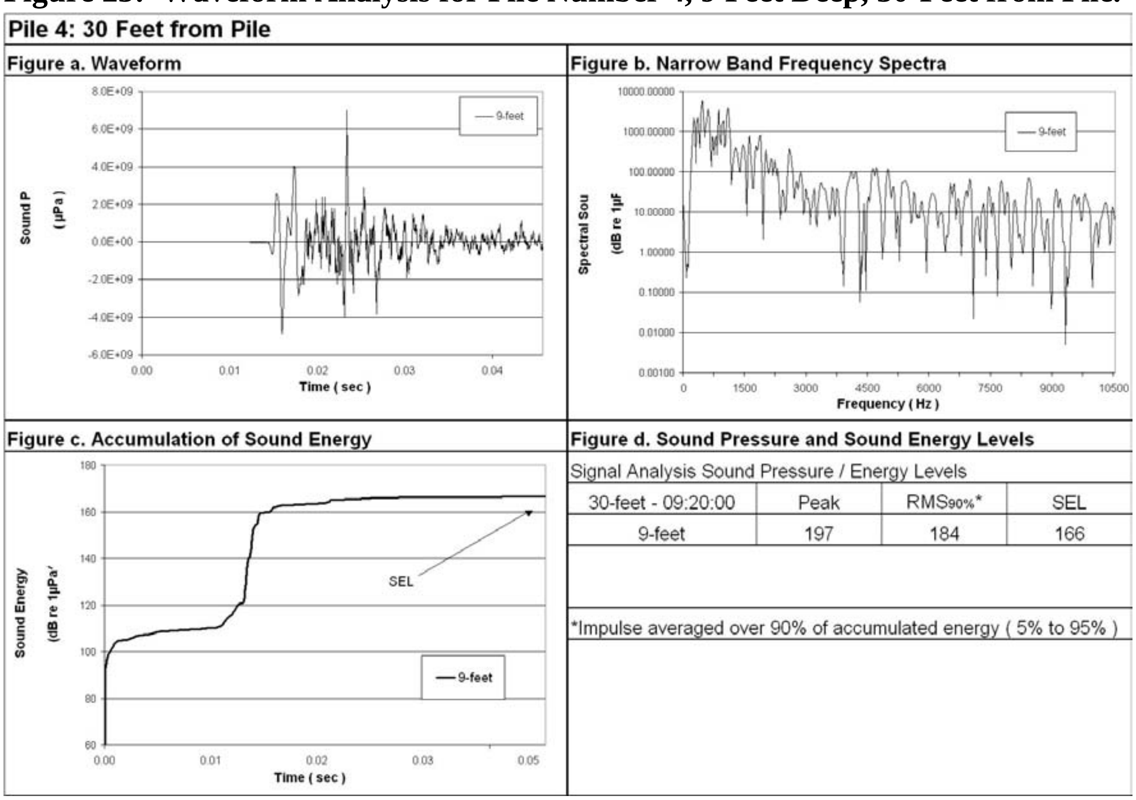
Measurements were made at 30 and 81 feet from the pile at 10 feet depth and one foot from the bottom. As can be seen in Figure 9 the contractor drove pile number 4 with reduced force for just under 6.5 minutes and then increased energy to the pile driver.

The peak value at 10 feet deep was 7.0 kPa (197 dB), RMS value was 184, and Sound Exposure Level (SEL) was 166 (Figure 23, a-d). One foot from the bottom the peak level was 7.9 kPa (198 dB), RMS value was 191 dB and the SEL value was 167 dB (Figure 24, a-d).

Measurements made 81-feet from the pile at 9-feet depth had a peak value of 4.0 kPa (192 dB), RMS value was 159, and Sound Exposure Level (SEL) was 145 (Figure 25, a-d). One foot from the bottom the peak level was 3.5 kPa (191 dB), RMS value was 174 dB and the SEL value was 161 dB (Figure 26, a-d).

In Figures 23b-26b below the acoustical frequency content of underwater impulses indicates that the dominant energy in each pile strike is between about 50 and 4000 Hz with most energy contained over the range of 0 to 1600 Hz.

Figure 23: Waveform Analysis for Pile Number 4, 9 Feet Deep, 30-Feet from Pile.



Signal Analysis Sound Pressure / Energy Levels

30-feet - 09:20:00	Peak	RMS90%*	SEL
9-feet	197	184	166

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

Figure 24: Waveform Analysis for Pile Number 4, 1-Foot from Bottom, 30-Feet from Pile.

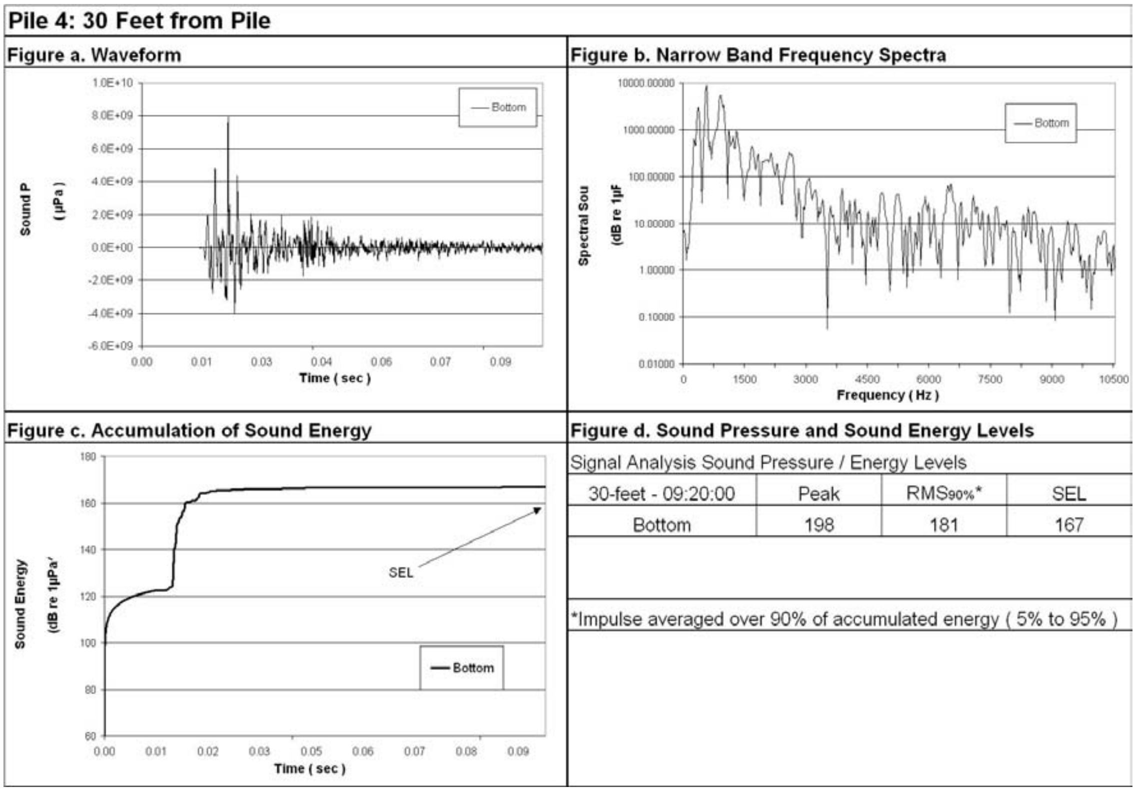


Figure 25: Waveform Analysis of Pile Number 4, 9-Feet Deep, 81-Feet from Pile.

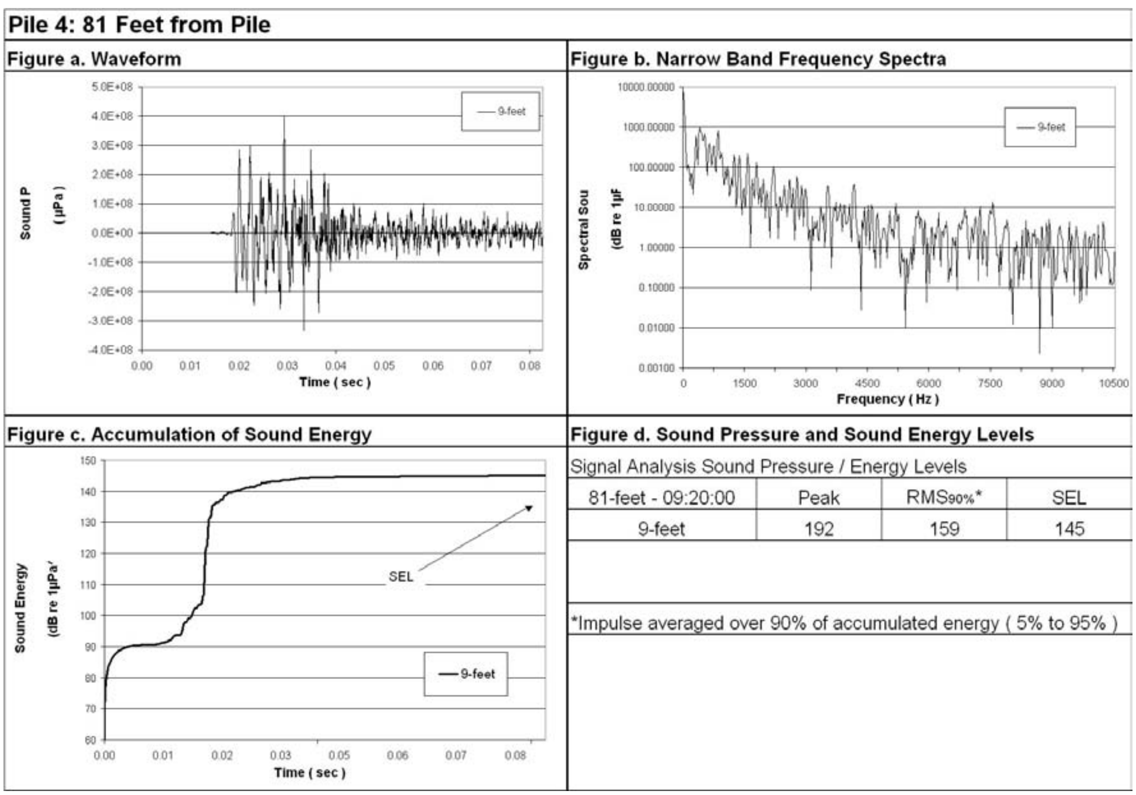
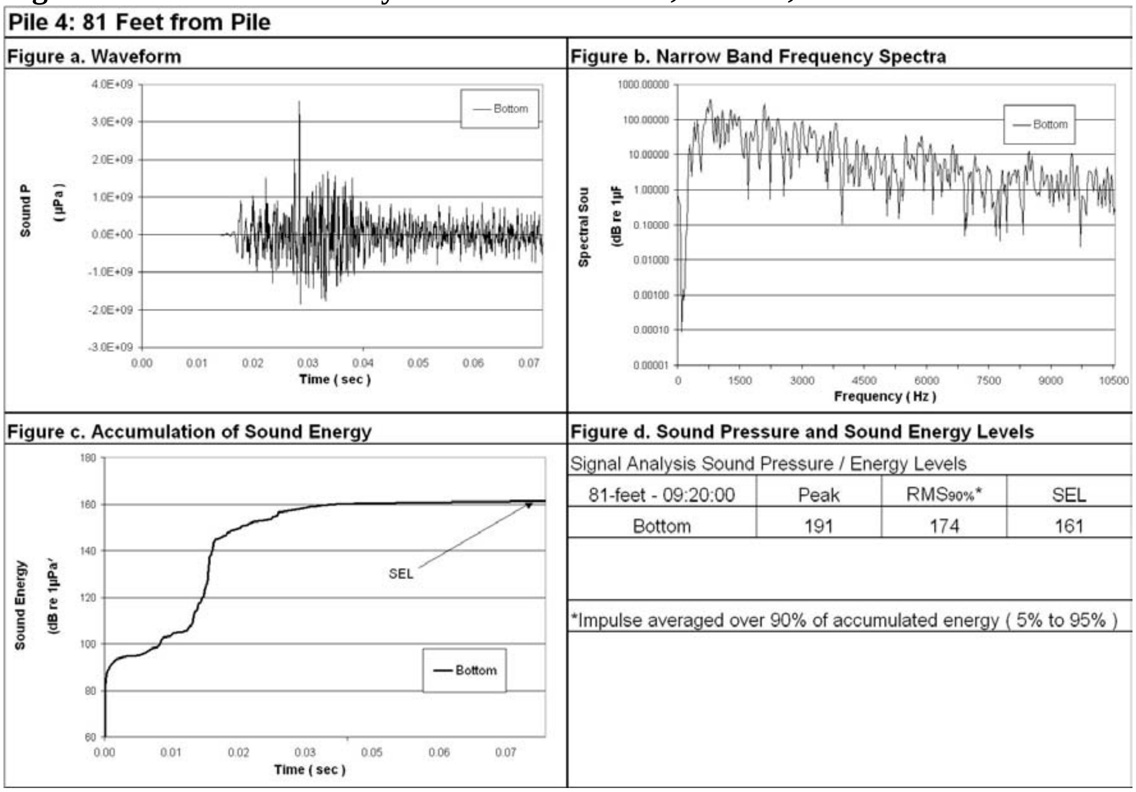


Figure 26: Waveform Analysis of Pile Number 3, Bottom, 81-Feet from Pile.



Examination of the waveforms for pile number 4 indicate a rise time of 2 milliseconds (msec). A moderately rapid fluctuation in underpressure to over pressure occurs within about 0.5 msec. The decay time of the impulse is relatively slow, lasting about 50 msec. Much of the energy associated with the impulse occurs within the first 40 msec.

There was a 4.5 kPa (11.5 dB) difference between the bottom and mid level measurements with the highest value measured at mid level.

Pile 5

Measurements were made at 30 and 74 feet from the pile at 9 feet depth and one foot from the bottom. As can be seen in Figure 10 the contractor drove pile number 5 with reduced force for just under five minutes and then increased energy to the pile driver .

The peak value at 9-feet depth was 6.8 kPa (197 dB), RMS value was 186, and Sound Exposure Level (SEL) was 169 (Figure 27, a-d). One foot from the bottom the peak level was 6.4 kPa (196 dB), RMS value was 182 dB and the SEL value was 167 dB (Figure 28, a-d).

Measurements made 74-feet from the pile at 9-feet depth had a peak value of 4.7 kPa (193 dB), RMS value was 179, and Sound Exposure Level (SEL) was 165 (Figure 29, a-d). One foot from the bottom the peak level was 3.4 kPa (191 dB), RMS value was 176 dB and the SEL value was 162 dB (Figure 30, a-d).

In Figures 27b-30b below the acoustical frequency content of underwater impulses indicates that the dominant energy in each pile strike is between about 50 and 4000 Hz with most energy contained over the range of 0 to 1600 Hz.

Figure 27: Waveform Analysis for Pile Number 3, 10 Feet Deep, 30-Feet from Pile.

Pile 5: 30 Feet from Pile

Figure a. Waveform

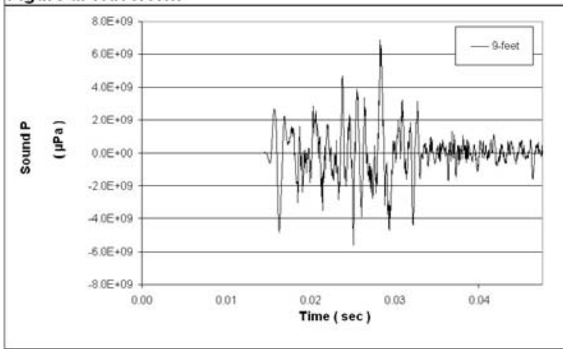


Figure b. Narrow Band Frequency Spectra

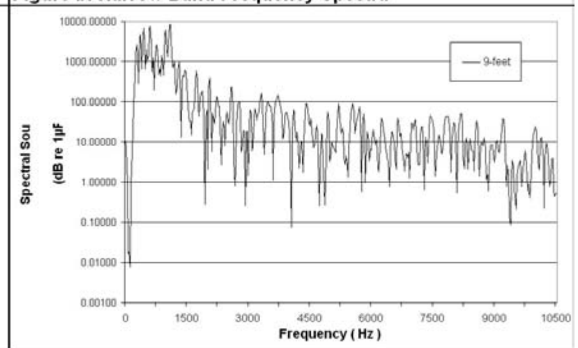


Figure c. Accumulation of Sound Energy

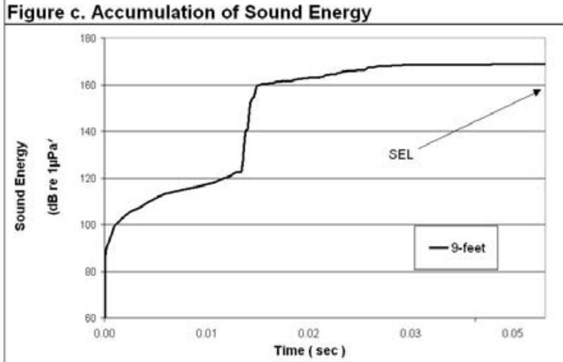


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

30-feet - 10:40:00	Peak	RMS90%*	SEL
9-feet	197	186	169

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

Figure 28: Waveform Analysis for Pile Number 5, 1-Foot from Bottom, 30-Feet from Pile.

Pile 5: 30 Feet from Pile

Figure a. Waveform

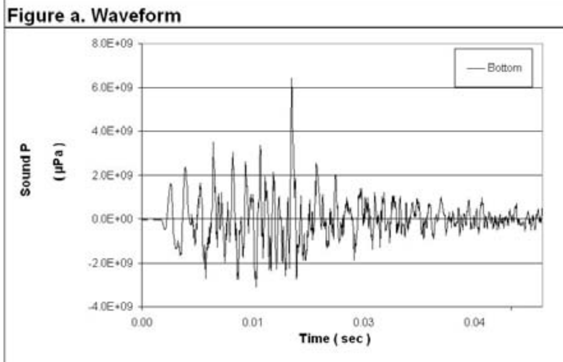


Figure b. Narrow Band Frequency Spectra

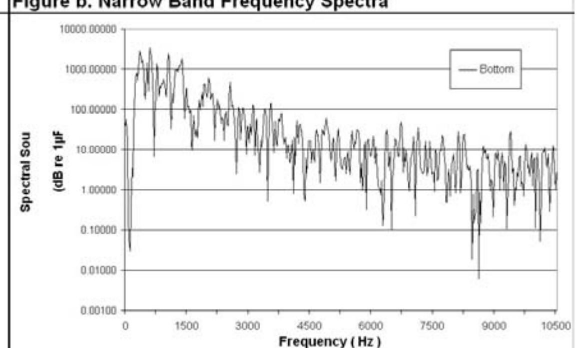


Figure c. Accumulation of Sound Energy

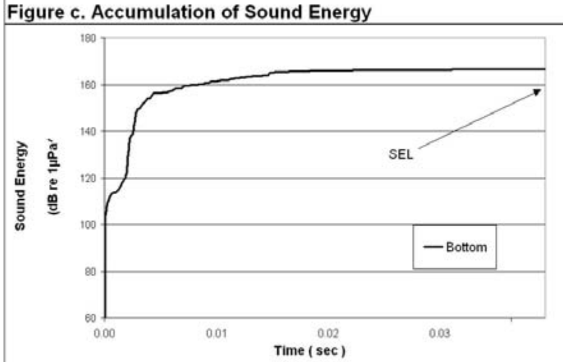


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

30-feet - 10:40:00	Peak	RMS90%*	SEL
Bottom	196	182	167

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

Figure 29: Waveform Analysis of Pile Number 3, 10-Feet Deep, 74-Feet from Pile.

Pile 5: 74 Feet from Pile

Figure a. Waveform

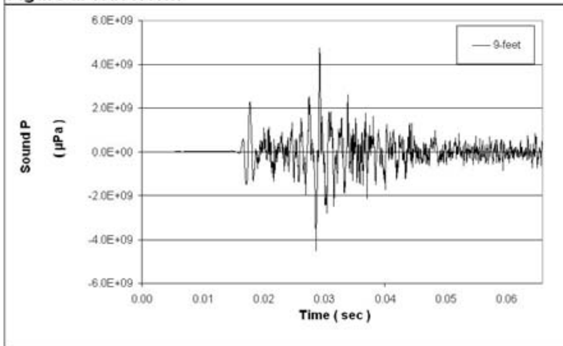


Figure b. Narrow Band Frequency Spectra

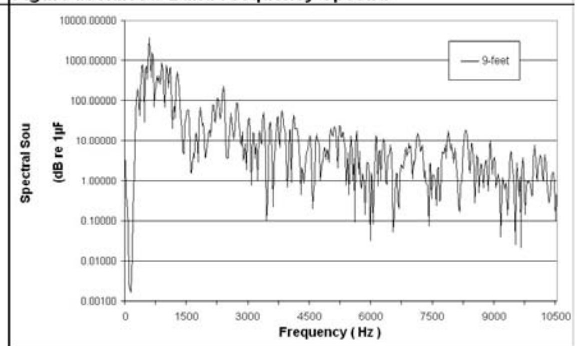


Figure c. Accumulation of Sound Energy

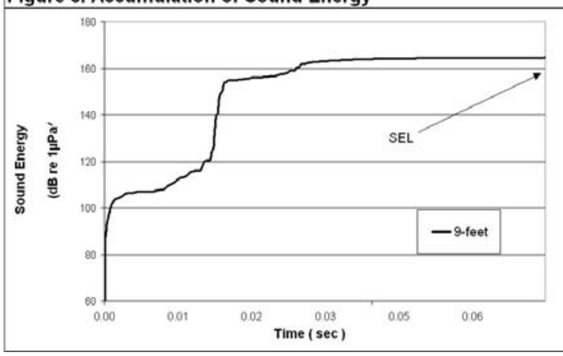


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

74-feet - 10:40:00	Peak	RMS90%*	SEL
9-feet	193	179	165

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

Figure 30: Waveform Analysis of Pile Number 5, Bottom, 74-Feet from Pile.

Pile 5: 74 Feet from Pile

Figure a. Waveform

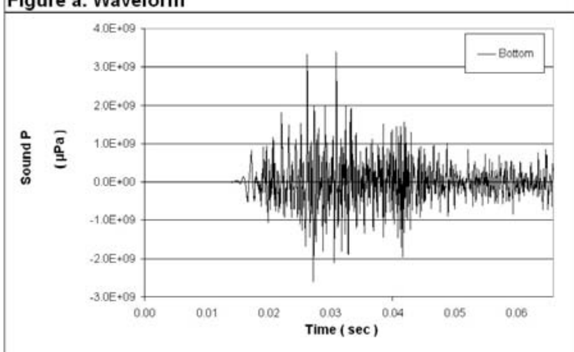


Figure b. Narrow Band Frequency Spectra

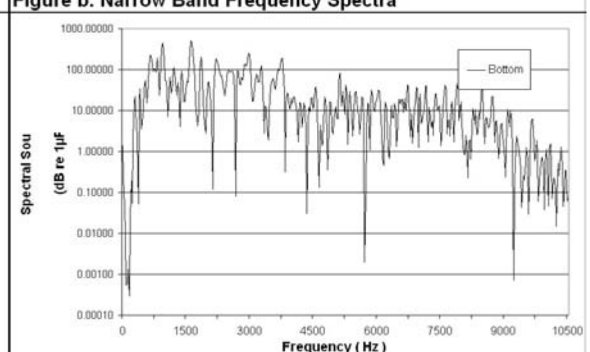


Figure c. Accumulation of Sound Energy

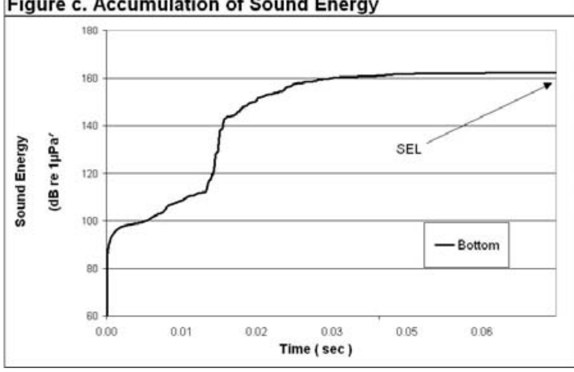


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

74-feet - 10:40:00	Peak	RMS90%*	SEL
Bottom	191	176	162

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

Examination of the waveforms for pile number 5 indicate a rise time of 2 milliseconds (msec). A moderately rapid fluctuation in underpressure to over pressure occurs within about 0.5 msec. The decay time of the impulse is relatively slow, lasting about 50 msec. Much of the energy associated with the impulse occurs within the first 33 msec.

There was a 4.5 kPa (11.5 dB) difference between the bottom and mid level measurements with the highest value measured at mid level.

Table 3: Summary of Pile Driving Strikes

Parameter	Pile 1	Pile 2	Pile 3	Pile 4	Pile 5
Number over Criterion	0	0	0	0	0
Number over 180 dB	>183[1]	>419[1]	431	460	404
Total Pile Strikes	>183	>419	431	460	404
Percent over Criterion	0%	0%	0%	0%	0%

[1] – Monitoring started approximately 15 seconds after driving started because deployment of hydrophones took longer than expected.

TURBIDITY

Turbidity measurements were made in the field during the pile driving activity down stream of the site. The results are shown in Table 4. There were no increases in turbidity found resulting from the pile driving activity.

Table 4: Summary of Water Quality Results

Station	Date	Turbidity (NTU)
3b	8/9/04	4.32
3a	8/9/04	5.67
2b	8/10/04	1.53
2a	8/10/04	3.28
2b	8/11/04	1.36
2a	8/11/04	2.43

BIOLOGICAL OBSERVATIONS

Juvenile 2-3 inch fingerlings (rainbow or steelhead based on a conversation with Craig Broadhead, WSDOT biologist) were observed swimming in the shallow water near the shoreline (3-4 inches depth) during pile driving. No changes in movement or normal swimming behavior was observed during pile driving. Between pile driving events fish (possibly carp) were observed jumping and feeding at the water surface.

CONCLUSIONS

Driving of 16-inch diameter, open-ended steel piles generated sound levels that appeared to be non-lethal to fish. No dead fish were observed and live juvenile fish observed at the shoreline appeared to not be adversely affected by the pile driving. Without any mitigation measures to reduce underwater peak sound levels, sound levels ranged from 3.4 kPa to 10.2 kPa (191 dB to 200 dB) at mid and bottom depths between 30 and 90 feet from the pile. Generally the highest sound levels were recorded at mid-water depth and at 30 feet from the pile.

Monitoring which took place a year ago at the same location where piles were being driven in six-inches of water or less resulted in sound levels much lower than these piles driven in 17-20 feet of water. According to Urick (1983) the propagation of sound underwater is dependent on the frequency of the sound. Sound wavelength is determined by dividing the speed of sound in water by the frequency. Then the wavelength is divided by 4 to determine the minimum water depth in which that wavelength will propagate. For example, according to the frequency content analysis performed above most of the sound energy is between 0 and 1600 Hz. Taking the worst case dividing the speed of sound in water (1500 m/s) by 1600 Hz gives 0.94 meters as the wavelength. Dividing this wavelength by 4 gives a minimum water depth of 0.2 meters or 0.66 feet (8 inches). This also means that all of the frequencies below 1600 Hz will not propagate in this depth of water. However, sound can be transmitted through the sediment (sound flanking) and dependent on the type of soil will be attenuated at different rates than in water.

Reyff et al. (2002) measured rise times of about 1 msec and attributed this short rise time to fish mortality. Research conducted by the Port of Vancouver (unpublished) has indicated that it is not necessarily how high the peak is but rather how fast the peak is achieved (i.e. how fast is the rise time). Hastings (2002) determined that some barotraumas injuries would be expected between 190 and 210 dB_{peak}. Use of bubble curtains to mitigate sound levels also increases the rise time to 2 msec or greater (Rickman, 2000). It is possible that increasing the rise time would result in reduced fish barotraumas injury. Peak sound levels during monitoring for this project ranged between 191 and 200 dB_{peak}. Rise times measured during this monitoring were approximately 2 msec or greater. This greater rise time observed may account for the lack of fish mortality observed.

It is recommended that future projects using open-ended steel piles 16-inches in diameter which are not being driven through bedrock should not require monitoring or mitigation because the rise times measured are greater than those which would be expected to cause barotraumas injuries to fish. This in combination with a seasonal in-water work window would provide adequate protection to fish.

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Urick, R.J. Principals of Underwater Sound. Ch. 7 *In:* The Noise Background of the Sea. Peninsula Publishing, Los Altos, CA 1983.