Final Report

Pile-Driving Noise Measurements at Atlantic Fleet Naval Installations:

28 May 2013–28 April 2016

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List of Abbreviated Terms

μPa	microPascal
APE	American Piledriving Equipment
cSEL	cumulative SEL
dB	decibel(s)
dB re 1 μPa	dB referenced to a pressure of 1 microPascal
ELCAS	Elevated Causeway
Hz	Hertz
In-lb	inches-pound(s)
kgm	kilogram-meter(s)
kNm	kilometer Newton
L_{eq}	Equivalent Sound Level
L_{peak}	Peak Sound Pressure Level
RMS	Root Mean Square
SEL	Sound Exposure Level
SLM	Sound Level Meter(s)
SPL	Sound Pressure Level

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Executive Summary

Current U.S. Navy waterfront infrastructure, specifically wood, steel, and concrete “piles” that support adjacent shore transportation corridors, requires constant maintenance and periodic replacement. When “pile-driving” construction is necessary, the Navy is accountable for impacts upon fish species listed as threatened or endangered under the federal Endangered Species Act, species managed under the essential fish habitat provisions of the Magnuson-Stevens Fisheries Management and Conservation Act, and marine mammals under the Marine Mammal Protection Act and federal Endangered Species Act. The potential for death or injury of fish and injury to marine mammals resulting from driving piles has elevated the public and resource agency concerns relative to effects on these various species.

In order to better assess the impacts of pile-driving activities, the U.S. Navy has collected data at six locations where 93 pile driving events occurred in which noise levels were measured over a 3-year period of airborne and underwater empirical acoustic noise-level data collected during pile-driving construction projects along the Mid-Atlantic corridor.

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1. Introduction

Tables 1 and 2 contain a summary of the pile-driving events**.** The driving of various types of piles was measured, including steel H-piles, steel sheet piles, timber piles, steel king piles, concrete piles, and various-sized steel shell piles. Noise data for diesel impact, vibratory, and pneumatic drop hammer were also collected.

Table 1. Summary of Impact Pile-Driving Activities

Pile Type and Size	Date	Hammer Type	Pile Location	Description of Work
24-inch concrete	29-May-13	ICE 220 diesel impact hammer	Craney Island	Proofed two concrete piles
24-inch concrete	21-Oct-14 25-Oct-14	Vulcan 010 pneumatic drop Hammer	Naval Station Norfolk	Set fender piles
48-inch steel	30-Sep-14	APE D70-52 diesel impact hammer	Philadelphia Naval Shipyard	Drove piles through holes cut in pier as part of the pier renovation
36-inch steel	1-Oct-14 2-Oct-14			
24-inch steel	26-Apr-16 27-Apr-16 28-Apr-16	APE D19-42 diesel impact hammer	JEB Little Creek Naval Station	Measured 12 steel shell piles driven as part of the ELCAS Construction

Table 2. Summary of Vibratory Pile-Driving Activities

Pile Type and Size	Date	Hammer Type	Pile Location	Description of Work
24-inch sheet piles	28-May-13 30-May-13	ICE-416	Craney Island	Piles were set as part of a retaining wall at a boat launch
H-piles		HPSI 250 XL		
Timber piles	27-Oct-14	HPSI 250 XL	Naval Station Norfolk	Piles were installed as part of a fender wall system
48-inch steel shell 36-inch steel shell	30-Sep-14 1-Oct-14 2-Oct-14	APE 200	Philadelphia Naval Shipyard	Drove piles through holes cut in pier as part of the pier renovation
48-inch king pile	9-June-15 11 June-15	APE 300	Naval Station Mayport	Constructing a retaining wall with king piles and sheet piles
24-inch Sheet pile				
24-inch steel shell	10-Sept-15 11-Sept-15	APE 150	JEB Little Creek Naval Station	Removing piles during the demolition of the ELCAS Project

This report is organized as follows: **Section 1** – Description of the Study Areas, **Section 2 –** Methods and Equipment, **Section 3 –** Descriptions of Measurements, **Section 4 –**Measurement Results and Analysis, and **Section 5 –** Discussion and Lessons Learned. A Glossary of Acoustic Terms and Acronyms is provided in **Section 6**.

Supplementary content includes: **Appendix A** – Time History of Pile Driving and Removal, **Appendix B** – one-third Octave Band Spectrum Data, and **Appendix C** – Time History and 1-Minute Airborne Data.

1.1 Description of the Project Study Areas

This section of the report outlines the different locations and provides a brief description of the types of piles for which underwater and airborne noise levels were measured and the type of pile-driving equipment that was used during the various pile-driving operations.

1.1.1 JEB Little Creek and Craney Island, 28 through 30 May 2013

Joint Expeditionary Base (JEB) Little Creek and Craney Island are located near Naval Station Norfolk near Norfolk, Virginia. Noise measurements were made during the installation of sheet piles and the installation and removal of H-piles at JEB Little Creek on 28 and 30 May, and during the short driving duration of concrete piles to verify their bearing capacity or proofing the piles at Craney Island on 29 May. On 28 May, noise levels were measured during installation of five sheet piles, the removal of one H-pile, and the installation of two H-piles. The sheet piles were installed and the H-piles were removed using an ICE-416 vibratory hammer with an eccentric moment of 25.3 kilogram-meters (2,200 inch-pounds [in-lb]). On 29 May, noise monitoring was completed on the proofing of two concrete piles at Craney Island. These piles were being driven to check their bearings and were struck 25 and 14 blows, respectively. The peak sound pressure level (SPL), root mean square (RMS) SPL, sound exposure level (SEL), and cumulative SEL (cSEL) were recorded at two locations—10 meters (33 feet) and approximately 50 meters (164 feet). The piles were driven in with an ICE-220 diesel impact hammer.

On 30 May, six sheet piles were installed, and nine H-piles were either installed or removed. The sheet piles were installed using an ICE-416 vibratory hammer. The three H-piles were also driven using this hammer, and two were removed using this hammer. The other four H-piles were installed or removed using a newer and quieter HPSI-250xl vibratory hammer with an eccentric moment of 28.7 kilogram-meters (kgm; 2,500 inch-pounds). The distant location meter was moved to the end of Pier 27 on the Navy station. This was approximately 190 meters (625 feet) from the work area.

1.1.2 Philadelphia Naval Shipyard, 30 September through 2 October 2014

Monitoring at the Philadelphia Naval Shipyard consisted of underwater and airborne noise monitoring for vibratory and impact driving of 91.4-centimeter (36-inch) and 121.2-centimeter (48-inch) steel shell piles. The piles driven were structural piles being driven to reinforce the existing pier. The water depth at the pile locations was approximately 12 meters (40 feet). There were two different sizes of piles driven. First the piles were set and installed with an American Piledriving Equipment (APE) Model 200 vibratory hammer eccentric moment of 50.69 kgm (4,400 in-lb.), and then the piles were driven to their final tip elevation utilizing an APE D70-52 diesel impact hammer, an energy rating between 117.21 kilonewton meters (kNm) (1,041,864 in-lb) and 234.42 kNm (2,083,728 in-lb). An aircraft carrier was to the west side of Pier 4, and a large ship was on the east side of Pier 2. The piles were driven through holes cut in the existing pier deck.

1.1.3 Naval Station Norfolk, 21 through 27 October 2014

Measurements at Naval Station Norfolk in Norfolk, Virginia, consisted of monitoring underwater and airborne noise levels during impact driving of 61-centimeter (24-inch) square concrete piles and vibratory driving of timber piles approximately 8-inches at the tip. The piles driven were fender piles, nonstructural, being driven to upgrade the fender system at Pier 4. Water depth at the pile locations was approximately 12 meters (40 feet). Pier 4 (where the pile driving occurred) is set behind a floating security curtain between Pier 5 to the north and Pier 3 to the south. On the north side of Pier 4, there was a Danish Naval ship moored, and the south side of Pier 4 was unoccupied. The piles were driven adjacent to the south side of Pier 4. The concrete piles were installed after the jetting/drilling using a Vulcan model 010 drop hammer. The timber piles were installed using a HPSI-250xl vibratory hammer with an eccentric moment of 28.7 kgm (2,500 in-lb).

1.1.4 Naval Station Mayport, 9 through 11 June 2015

This project consisted of measuring underwater and airborne noise levels for pile driving at Naval Station Mayport in Jacksonville, Florida. The measurements occurred from 9 through 11 June 2015. Both 96.5 × 45.7-centimeter (38 × 18-inch) king piles and 122-centimeter (48-inch) sheet piles were installed. The sheet piles were made up of four individual 12–inch pieces that were connected and driven as one unit. All pile-driving was accomplished using an APE 300 vibratory hammer; which has an eccentric moment of 66.25 kgm (5,750 in-lb). Noise levels were measured for 15 king piles and 17 sheet piles. The hydroacoustic monitoring took place at three distances from the pile-driving—"near," "mid-range," and "distant"—which all varied between and within days. The near and mid-range locations were manned, and the distant location had an autonomous recording system in place. Four different measures of maximum noise were taken—RMS SPL, peak SPL, SEL, and cSEL.

1.1.5 JEB Little Creek Naval Station, 10 through 11 September 2015 ELCAS Removal

This project consisted of monitoring the removal of steel shell piles associated with a training exercise related to the removal of the Elevated Causeway (ELCAS) at JEB Little Creek, Norfolk, Virginia. On 10 and 11 September 2015, multiple 61-centimeter (24-inch) steel pipe piles were removed. All pile-extractions were accomplished using an APE 150 vibratory driver extractor; which has an eccentric moment of 23.35 kgm (2,200 in-lb). Noise levels were measured for 13 piles. The hydroacoustic monitoring took place at three distances from the pile removal—"near," "mid-range," and "distant —which all varied between and within days. The near and mid-range positions were manned, and the distant position had an autonomous recording system in place. Four different measures of sound were made—RMS SPL, peak SPL, SEL, and cSEL.

1.1.6 JEB Little Creek Naval Station, 26 through 28 April 2016 ELCAS Construction

This project consisted of measuring the underwater and airborne noise levels for the installation of piles associated with the construction of the ELCAS at JEB Little Creek, Norfolk, Virginia. On 26, 27, and 28 April 2016, multiple 61-centimeter (24-inch) diameter steel pipe piles were installed. All pile-driving was accomplished using an APE D19-42 diesel impact hammer; which has a maximum rated energy of 47,132 ft-lb (63.63 kNm) at setting 4. Noise levels were measured for nine piles. The hydroacoustic monitoring took place at three distances from the pile installation: near was on the pier 10 meters (33 feet) from the pile, mid-range was on a vessel 125 meters (410 feet) from the pile, and far was located 500 meters (1,640 feet) from the pile. The near and mid-range positions were manned and the far position had an autonomous recording system in place. Four different measures of sound were made—RMS SPL, peak SPL, SEL, and cSEL.

2. Monitoring Equipment

Measurements were made by both manned systems and autonomous or unmanned systems; **Figure 1** shows a sample of each type of equipment used. Reson Model TC-4013 and/or Reson Model TC-4033 hydrophones with PCB in-line charge amplifiers (Model 422E13) were used. For attended systems, the hydrophones were fed through an in-line charge amplifier into Larson Davis Model 831 Precision Sound Level Meters (LDL 831 SLM). The LDL 831 then outputs the signal to a Roland R-05 solid-state digital data recorder. The output of the LDL 831 can be adjusted. For unmanned systems that involved signal recordings only, PCB multi-gain conditioners (Model 480M122) were used with the hydrophones and in-line charge amplifier. The multi-gain signal conditioner provides the ability to increase the signal strength (i.e., add gain) so that measurements are made within the dynamic range of the instruments used to analyze the signals. Two types of hydrophones were used due to the differences in sensitivity and the availability of equipment for this program.

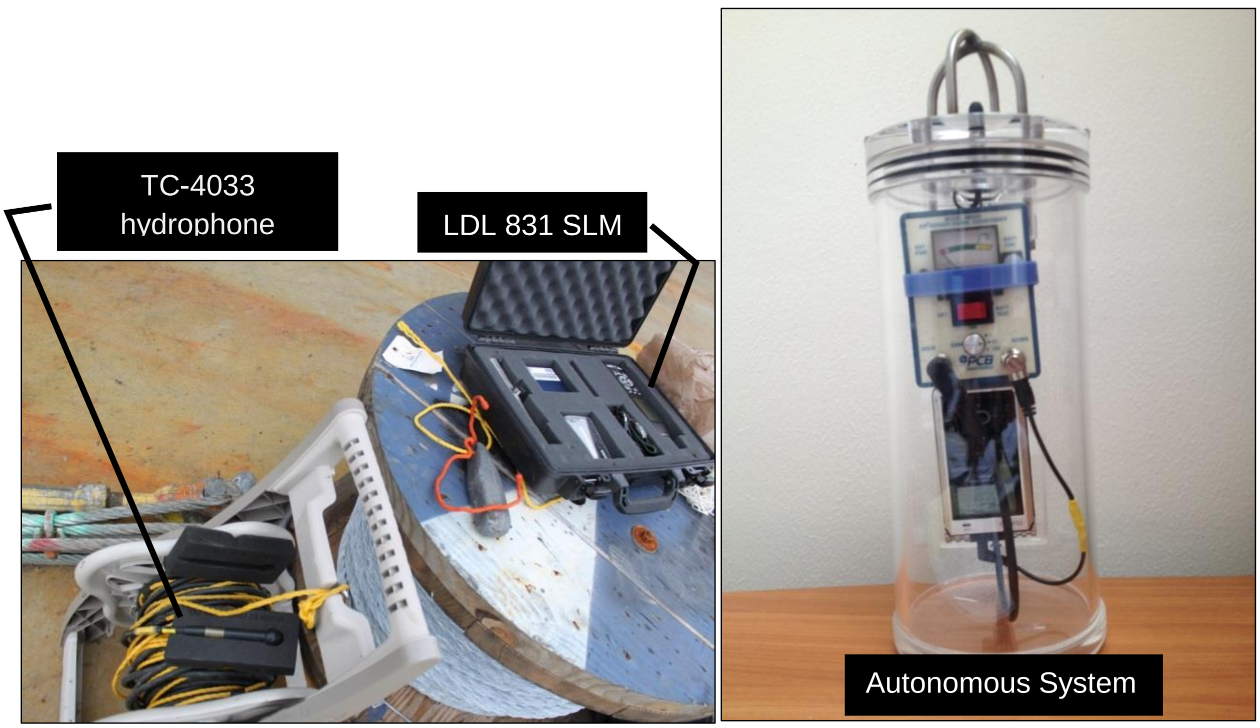

Figure 1. Typical Underwater Monitoring Equipment

The TC-4013 hydrophone is approximately 13 decibels (dB) less sensitive than the TC-4033 and better suited for measuring higher sound levels without overloading the measurement system. For this reason, the TC-4013 hydrophone was used for the near measurement sites. The TC-4033 hydrophones have a greater sensitivity and are better suited for the measurement of low-level signals and, therefore, were deployed at positions farther from the pile driving where low-amplitude signals were expected.

During impact driving, the maximum peak SPL (LZ_{peak}), impulse RMS SPL (LZI_{max}), and the 1-second SEL (LZ_{eq}) were measured "live" using the LDL 831. During vibratory driving, the

LZ_{peak} and the fast RMS SPL (LZF_{max}) were measured "live" using the LDL 831. The LDL 831 SLM provided measurements of the un-weighted results for each data type, including the one-third octave band spectra for the 1-second LZ_{max}. Additional analyses of the acoustical impulses were performed using the LDL 831 SLMs as well. The LDL 831 captures the signal and stores the measurement data that are retrieved at the completion of a day of measurements.

Airborne measurements were made using 0.5-inch G.R.A.S. Model 40AQ pre-polarized random-incidence microphones. The signals were fed into LDL 820 SLM. The systems were calibrated with a Larson Davis Model CAL 200 acoustic calibrator. The microphones were calibrated at the beginning and end of each day. Pre-event and post-event calibration levels were within 0.1 dB.

2.1.1.1 UNDERWATER SYSTEM ACOUSTIC CALIBRATION

The measurement systems were calibrated prior to use in the field with a G.R.A.S. Type 42AA pistonphone and hydrophone coupler. A pistonphone is an acoustical calibrator used to generate a precise sound pressure for the calibration of instrumentation microphones. The pistonphone, when used with the hydrophone coupler, produces a continuous 145.3 dB re 1 µPa (dB referenced to a pressure of 1 microPascal) tone for the TC-4013 hydrophones and 136.4 dB re 1 µPa tone for the TC-4033 hydrophones at 250 Hertz (Hz). The tone measured by the SLM was recorded at the beginning of the recordings. The system calibration status was checked at the beginning of each measurement day by both measuring the calibration tone and recording the tone on the solid-state digital data recorder. The pistonphones were certified at an independent facility.

All field notes were recorded in water-resistant field notebooks. Such notebook entries include calibration notes, measurement positions (i.e., distance from source, depth of sensor), measurement conditions (e.g., currents, sea conditions, etc.), system gain settings, and the equipment used to make each measurement. Notebook entries were copied after each measurement day and filed for safekeeping. Digital recordings were also copied and stored for subsequent analysis, if needed.

2.1.2 Airborne Measurement Methods and Equipment

The following sections describe methods and equipment used in monitoring airborne sounds produced by pile driving. Airborne sound levels were measured at one position, typically on the pier approximately 15 meters (50 feet) from the pile driving.

3. Description of Measurements

3.1 Underwater Sound Descriptors

The acoustic monitoring program reports data in several required formats, depending on the type of pile driving and the type of acoustic measurement. Impact pile driving produces pulse-type sounds, while vibratory pile installation produces a more continuous type of sound.

For impact pile driving, data provided include the one-third octave band frequency spectrum, peak SPL, RMS SPL, and single-strike and cumulative SELs. For vibratory driving, data reporting included the average one-third octave band frequency spectrum over the entire pile-driving event. Additionally, the 1-second Equivalent Sound Level (L_{eq}) data during the pile-driving events were averaged in 10-second intervals.

For impact driving, the peak SPL is the highest instantaneous level of the measured waveform for every one of the 1-second time increments, which could be a negative or positive pressure (LZ_{peak}). The RMS SPL for each is computed by averaging the squared pressures over the amount of time required to achieve 90 percent of the total sound energy. However, this requires a considerable effort to analyze each pile strike individually. Alternatively, the maximum impulse level for each second of pile driving is reported. The impulse level is an RMS SPL with a 35-millisecond time constant. The time constant is approximately the same time duration in which most acoustic energy in a pile-driving acoustical pulse is contained. Use of this descriptor allows for the direct measurement of pulsed-RMS levels in the field. For this project, the RMS SPL was directly measured by using the precision SLM setting of “maximum impulse” and is denoted in this report as LZI_{max}. In this report, LZ_{eq}, LZ_{peak}, and LZI_{max} are expressed in dB re 1 µPa. In addition, the un-weighted SEL for each second was measured. SEL is a common unit of sound energy used in airborne acoustics to describe short-duration events. The units are dB referenced to a pressure of 1 microPascal squared-second (dB re 1 μPa^2-second). The total sound energy in an impulse accumulates over the duration of the impulse and the maximum level accumulated is the SEL for that event. SEL is reported by the second, and for an entire impact pile-driving event. In this report, both the single-strike SEL and the cSEL were measured.

3.2 Airborne Sound Descriptors

Un-weighted and/or A-weighted airborne data were collected. During data collection, either 1-second or 1-minute intervals were used for measuring airborne L_{eq} data. The maximum level of the “fast” RMS meter response over the 1-second intervals was also identified ($L_{max(1\text{-second})}$). These descriptors were used for both the un-weighted and A-weighted data during vibratory and impact driving.

3.3 Pile Driving and Acoustic Monitoring Events

Pile-driving activities and acoustic monitoring events are summarized at the end of the Introduction in **Tables 1 and 2**. During impact and vibratory pile driving, distances between the piles and the measurement locations were recorded (summarized in **Table 3 in Section 3.1.1 and Table 5 in Section 3.1.3**).

Underwater sound measurements were conducted for 35 piles driven with an impact hammer, which included 23 steel shell piles and 12 concrete piles. There were 93 piles driven with an vibratory hammer monitored consisting of 33 sheet piles, 24 steel shell piles, 16 king piles, 9 timber piles, and 7 H-pile installations and 4 H-pile removals. Airborne sound measurements were made for each of these events. **Appendix B** contains the results for all the impact pile driving of production piles. **Appendix C** contains results for vibratory pile driving of production piles. The airborne data for production piles are provided in **Appendix D**. All results are summarized in **Section 4**.

3.3.1 Background/Ambient Sound Data

Example of Ambient Underwater Sound Data

Ambient levels were measured prior to and following pile-driving events at each of the distant measurement locations. Although ambient measurements were also made before and after pile driving at the near positions, those systems were set up to measure higher amplitude pile-driving sounds than the distant measurement systems. As a result, ambient levels before and after pile-driving conditions likely contain electronic instrument noise as well. Typically, measurements began several minutes before pile driving and continued several minutes after pile driving (see Time History Plots in **Appendices B** and **C** for production piles). There were exceptions when pile driving started without notification or when piles were driven in quick succession.

If sound levels measured during pile driving were abnormally high due to inadequate testing conditions, such as strong water currents, the same high levels would appear in the ambient data as well, proving not to be caused by pile driving. Furthermore, by taking ambient measurements before and after pile-driving events, effects of the changing environmental conditions on the results were observed. These ambient data are discussed in the pile-driving results sections. The ambient data were analyzed as RMS levels over a given time period. **Figure 2** represents typical ambient data from the 1-second L_{eq} measurements taken at two measurement locations on 9 June 2015, between the vibratory installations of sheet piles at Naval Base Mayport.

The data in **Figures 2 and 3** were collected on 9 June 2015 from 13:23:00 to 13:34:00. Conditions during ambient testing were overcast with calm winds and little water disturbance. The frequency spectra shown in **Figure 3** indicate that ambient levels at the 10-meter (33-foot) measurement site are dominated by sounds below 30 Hz and above 1,000 Hz, while at the 200-meter (650-foot) measurement site, the ambient levels are dominated by sounds above 500 Hz. Ambient results varied with the testing conditions throughout the course of the project. These variations during any given pile-driving event are discussed in the subsequent sections.

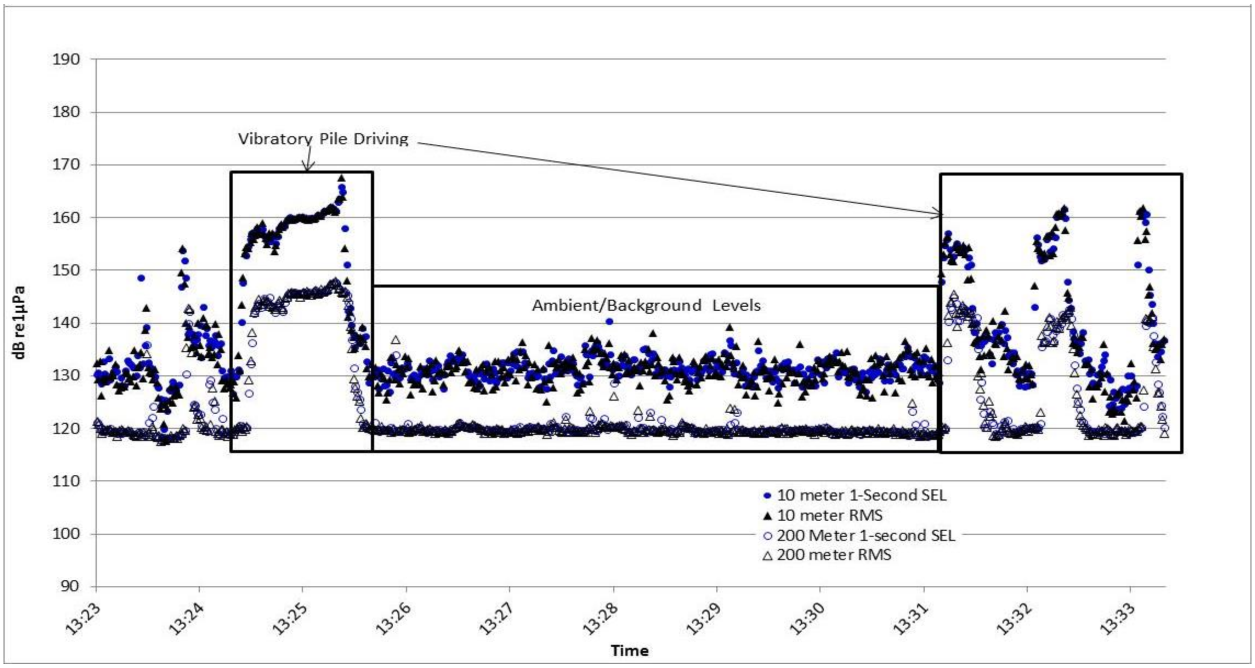

Figure 2. Sample of Ambient/Background Levels

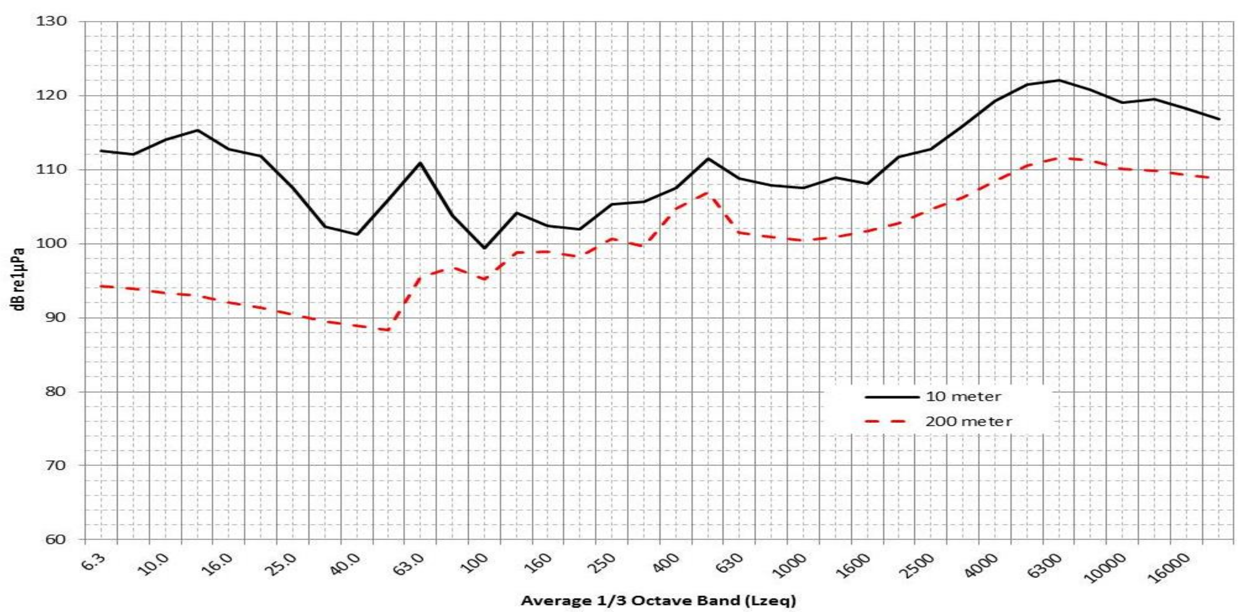

Figure 3. Sample of 1/3 Octave Band Spectra

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4. Measurement Results and Analysis

4.1 Summary of Underwater Sound Monitoring Data

4.1.1 Vibratory Pile Driving

Noise monitoring was conducted during a total of 93 vibratory pile installation or removal events— thirty three sheet piles, sixteen king piles, nine timber piles, eleven H-piles, thirteen 24-inch steel shell piles, eight 36-inch steel shell piles, and three 48-inch steel shell piles. Sound levels generated by vibratory pile installations varied considerably during the driving of an individual pile, and from pile to pile. This section discusses the results of the data analysis performed for vibratory pile-driving events.

Table 3 summarizes the daily results of RMS SPLs measured during vibratory pile driving throughout the different locations during the project. Data are summarized for each measurement location. The 10-second RMS averaged values are what would be used to determine the extent of the underwater isopleths relative to species-specific exposure criteria. During all of the pile-driving events, the distances to the 190-dB RMS level and 180-dB RMS level, as well as the injury thresholds for marine mammals, were always 10 meters (33 feet) or less. The average sound levels over the duration of the pile-driving event, and the maximum level during the pile-driving event, are shown at each location where data were obtained. The RMS sound pressure levels were averaged in consecutive 10-second periods throughout the pile-driving event.

Vibratory pile-driving acoustical data are provided in graphical format in **Appendix A**. A time history plot of the 1-second sound pressure levels is provided for each location and pile type. The average RMS was calculated by taking the average of the 10-second RMS levels for the entire event, any breaks in the driving were not part of the calculation. These values are shown in **Table 3.** Also shown in **Table 3** are the measured distances of each measurement.

4.1.1.1 JEB LITTLE CREEK AND CRANEY ISLAND, 28 MAY THROUGH 30 MAY 2013

Measurements at the JEB Little Creek included the installation of 11 sheet piles and the removal or installation of 12 H-piles. Measurements were made at distances ranging from 10 meters (33 feet) to 200 meters (656 feet). The levels from the sheet pile installation and the H-pile installation and removal were not perceivable above the background levels at the distant location which was across the harbor at the end of Pier A in the Little Creek Marina, approximately 197 meters (650 feet) from the pile driving. The distant location meter was moved to the end of Pier 27 on the Joint Expeditionary Force Base Little Creek, a location approximately 190 meters (625 feet) from the work area. Most of the afternoon data at the 190-meter location was not detectable above the background levels. In the morning, when the water was a little calmer and there was less activity on the docks, the sheet pile installation was detectable above the background levels. The RMS levels ranged from around 115 dB to 121 dB re 1µPa. For the vibratory driving/removal only the root mean square (RMS) was reported. The sheet piles were installed using an ICE-416 vibratory hammer with an eccentric moment of 25.3 kgm (2,200 in-lb), the three H-piles were driven using this hammer and two were removed using this hammer. The other four H-piles were installed or removed using a newer and quieter HPSI-250xl vibratory hammer with an eccentric moment of 28.7 kgm (2,500 in-lb.).

Table 3. Statistics of 1-second and 10-second RMS SPL (dB re 1 μPa) for Vibratory Pile-Driving

Location	Date	Pile Type and Size	Duration (mm:ss)	Distance (meters)	1-second RMS SPL		10-second RMS SPL	
					Maximum	Average	Maximum	Average
Little Creek	28 May 2013	Sheet pile	04:48	11	150	136	149	131
		Sheet pile	06:45	11	151	146	150	146
		Sheet pile	09:48	11	150	147	150	147
		Sheet pile	07:34	9	173	162	170	162
		Sheet pile	01:46	9	162	158	161	158
		H-pile removal	01:48	10	147	143	147	143
		H-pile installation	09:50	10	162	147	153	148
Little Creek	30 May 2013	Sheet pile	03:54	11	170	161	166	163
		Sheet pile	00:48	11	160	152	156	153
		Sheet pile	00:54	11	163	159	162	161
		Sheet pile	01:30	11	164	159	163	157
		Sheet pile	00:36	11	160	154	155	154
		Sheet pile	01:36	11	167	162	166	162
		H-pile installation	00:40	13	152	140	148	143
		H-pile removal	00:58	13	153	149	150	150
		H-pile installation	02:33	19	145	138	140	138
		H-pile removal	02:13	21	154	141	147	142
		H-pile installation	00:58	15	154	147	149	148
		H-pile installation	07:01	21	140	129	138	129
		H-pile installation	01:26	21	136	133	136	133
		H-pile removal	01:31	21	149	138	147	139
		H-pile installation	03:33	21	144	139	143	139
Philadelphia	30 Sept. 2014	48-inch steel	16:16	10	168	162	167	162
				125	146	134	145	134
		48-inch steel	07:23	10	161	157	160	157
				125	140	137	139	136
		48-inch steel	04:08	10	165	157	163	157
				125	142	135	141	135
Philadelphia	01 Oct. 2104	36-inch steel	02:53	10	166	156	162	156
		36-inch steel	03:53	10	169	157	165	157
		36-inch steel	70:19	10	158	149	157	149

Location	Date	Pile Type and Size	Duration (mm:ss)	Distance (meters)	1-second RMS SPL		10-second RMS SPL	
					Maximum	Average	Maximum	Average
Philadelphia	02 Oct. 2014	36-inch steel	05:20	10	158	151	156	151
				200	125	117	122	117
		36-inch steel	5:30	10	157	151	154	151
				200	120	112	116	112
		36-inch steel	6:38	10	154	147	152	147
				200	128	118	128	118
		36-inch steel	2:55	10	156	146	154	147
				200	133	123	129	123
		36-inch steel	3:47	10	159	154	157	154
				200	131	125	130	125
Norfolk	27 Oct. 2014	Timber pile	01:05	23	142	137	139	138
				50	130	128	129	127
		Timber pile	01:22	19	144	138	142	139
				46	132	129	130	129
		Timber pile	00:37	17	141	138	138	138
				44	132	130	132	130
		Timber pile	00:41	13	160	149	159	149
				75	136	132	135	132
		Timber pile	00:26	11	166	163	164	163
				72	140	138	138	137
		Timber pile	00:18	10	164	162	162	162
				70	142	139	140	139
		Timber pile	00:31	12	168	163	163	163
				68	140	136	136	136
		Timber pile	00:34	10	166	165	166	165
				65	140	138	136	136
		Timber pile	00:24	9	170	165	156	165
				63	142	137	138	137

Location	Date	Pile Type and Size	Duration (mm:ss)	Distance (meters)	1-second RMS SPL		10-second RMS SPL	
					Maximum	Average	Maximum	Average
Mayport	9 June 2015	King pile	32:35	12	157	142	153	140
				110	131	126	130	126
		King pile	13:13	10	158	142	153	143
				110	134	127	132	127
		King pile	10:11	9	159	148	158	149
				240	130	124	128	125
		King pile	08:45	10	161	151	159	151
				230	133	124	129	125
		King pile	08:23	9	164	156	161	157
				235	133	123	125	123
		King pile	07:34	10	166	155	165	157
				110	134	128	132	129
		King pile	46:22	13	169	163	169	163
				115	145	133	144	133
		Sheet pile	00:13	12	ND	ND	ND	ND
				190	151	146	150	146
		Sheet pile	00:14	10	D	ND	ND	ND
				205	145	140	141	141
		Sheet pile	00:15	9	162	156	159	159
				205	145	136	141	141
		Sheet pile	00:12	10	158	153	155	155
				205	143	134	139	139
		Sheet pile	00:13	9	160	154	157	157
				205	147	138	143	143
		Sheet pile	00:12	10	158	151	154	154
				205	142	133	138	138
		Sheet pile	00:13	10	156	150	155	153
				205	142	132	138	137
		Sheet pile	00:50	8	173	147	168	148
				205	152	132	150	134
		Sheet pile	01:01	9	168	157	163	159
				205	148	143	147	144

Location	Date	Pile Type and Size	Duration (mm:ss)	Distance (meters)	1-second RMS SPL		10-second RMS SPL	
					Maximum	Average	Maximum	Average
Mayport	9 June 2015 (continued)	Sheet pile	00:18	10	156	150	154	153
				205	146	138	142	141
		Sheet pile	00:18	9	162	152	159	157
				205	142	138	140	138
		Sheet pile	00:08	9	162	146	155	155
				205	141	136	136	136
Mayport	10 June 2015	King pile	07:49	10	149	146	148	146
				100	132	127	130	127
		King pile	06:10	13	147	141	146	145
				100	132	127	130	127
		King pile	07:49	10	149	143	149	144
				100	135	131	134	131
				420	126	125	126	125
		King pile	10:09	10	151	145	149	146
				100	138	130	134	130
				420	128	124	126	124
		King pile	07:20	10	148	144	146	145
				100	136	131	134	131
				420	126	123	124	124
		King pile	10:32	10	150	143	147	144
				100	134	129	133	129
				420	126	123	124	123
		King pile	30:19	10	149	144	148	145
				100	135	131	134	131
				420	131	123	128	123
		King pile	28:09	10	158	151	156	151
				100	148	138	146	139
				420	139	127	135	127

Location	Date	Pile Type and Size	Duration (mm:ss)	Distance (meters)	1-second RMS SPL		10-second RMS SPL	
					Maximum	Average	Maximum	Average
Mayport	11 June 2015	King pile	02:32:56	10	164	151	163	151
				110	150	136	149	136
				400	139	130	139	130
		Sheet pile	00:22	10	159	154	159	156
				110	146	140	146	142
		Sheet pile	00:18	10	161	150	161	155
				110	149	136	149	141
		Sheet pile	00:17	10	158	148	158	153
				110	145	135	145	140
		Sheet pile	00:26	10	167	161	167	164
				110	150	144	150	147
		Sheet pile	00:22	10	162	154	162	157
				110	147	139	147	142
		Sheet pile	00:23	10	169	161	169	166
				110	155	146	155	151
		Sheet pile	00:30	10	167	157	167	161
				110	151	145	151	147
		Sheet pile	00:15	10	160	150	160	155
				110	146	136	146	142
		Sheet pile	00:17	10	164	157	164	161
				110	151	146	151	148
		Sheet pile	00:17	10	160	150	160	153
				110	148	141	148	143
Little Creek	10 Sept. 2015	24-inch steel	04:35	10	170	148	164	148
				86	134	130	133	130
		24-inch steel	03:36	12	169	146	160	147
				84	154	131	145	132
		24-inch steel	02:53	16	162	143	159	143
				80	150	134	145	134
		24-inch steel	01:28	16	159	140	151	141
				80	148	129	141	130
		24-inch steel	01:26	9	156	147	153	149
				87	134	126	131	127

Location	Date	Pile Type and Size	Duration (mm:ss)	Distance (meters)	1-second RMS SPL		10-second RMS SPL	
					Maximum	Average	Maximum	Average
Little Creek	10 Sept. 2015 (continued)	24-inch steel	03:29	13	172	142	166	146
				83	156	130	150	132
		24-inch steel	01:48	17	163	141	156	141
				79	152	130	145	131
		24-inch steel	01:00	12	158	145	153	146
				84	143	128	137	129
Little Creek	11 Sept. 2015	24-inch steel	00:57	14	167	141	160	142
				81	149	128	142	130
				300	144	124	138	125
		24-inch steel	01:18	11	171	147	167	147
				78	155	133	149	132
				300	147	128	142	127
		24-inch steel	01:36	16	164	140	154	142
				82	150	130	135	129
				300	142	126	129	125
		24-inch steel	01:20	11	166	148	161	149
				81	149	134	141	133
				300	146	129	138	129
		24-inch steel	01:06	11	169	147	163	148
				81	152	133	144	132
				300	146	130	141	130

The RMS levels varied greatly with the sheet piles being driven. The 10- second average RMS level ranged from 131 dB to 163 dB and the average one-second RMS levels ranged from 136 to 161 dB. The averages were over the entire duration of the sheet pile installation. Most of the drives were fairly short in duration the driving time ranged from 36 seconds to 9 minutes and 48 seconds, the longer duration drives were on the first day of the project the driving times were significantly shorter as the crew improved their techniques. For the H-Piles that were monitored the average 10-second RMS levels ranged from 139 dB to 150 dB for the removal of the H-piles and from 129 dB to 148 dB during the installation of the H-piles. The duration of the removal of the H-piles ranged from 58 seconds to 2 minutes and 13 seconds. The driving time for the H-piles ranged from 40 seconds to 9 minutes and 58 seconds. **Table 4** shows the average RMS SPL for the pile driving at JEB Little Creek. The data has been normalized to 10 meters based on the average attenuation rates shown in **Table 9 in Section 4.1.2**.

Table 4. Average 1-second and 10-second Broadband RMS SPL (dB re 1 μPa) for Vibratory Pile-Driving Normalized to 10 meters at JEB Little Creek

Pile Type and Size	Distance (meters)	Average 1-second RMS SPL	Average 10-second RMS SPL
Sheet pile	10	155	154
H-Pile Installation	10	146	147
H-Pile Removal	10	149	150

4.1.1.2 PHILADELPHIA NAVAL SHIPYARD, 30 SEPTEMBER THROUGH 2 OCTOBER 2014

Measurements were made during the vibratory driving of three 48-inch steel shell piles and eight 36-inch steel shell piles. Unlike the sheet piles and H-piles measured at JEB Little Creek these medium sized steel shell piles tended to be a little more uniform in the levels measured, while there was some variation it was less than the other types of piles. During the vibratory pile driving measurements taken at the 10-meter (33-foot) location, the average 10-second RMS values for the 48-inch piles ranged from 157 to 162 dB and the average 10-second RMS values for the 36-inch piles ranged from 147 to 156 dB. An APE model 200 vibratory hammer with an eccentric moment of 50.69 kgm (4,400 in-lb) was used for the vibratory installation of the piles. **Table 5** shows the average levels measured at 10 meters for the piles installed at the Philadelphia Naval Shipyard with the vibratory hammer.

Table 5. Average 1-second and 10-second Broadband RMS SPL (dB re 1 μPa) for Vibratory Pile-Driving Measured at 10 meters at Philadelphia Naval Shipyard

Pile Type and Size	Distance (meters)	Average 1-second RMS SPL	Average 10-second RMS SPL
36-inch Steel Shell	10	151	152
48-inch Steel Shell	10	159	159

4.1.1.3 NAVAL STATION NORFOLK, 21 THROUGH 27 OCTOBER 2014

During this project, there was a delay during the measurements due to an extremely high tide that flooded the docks where the work was supposed to occur. This high tide was caused by a combination of factors, including a strong storm surge from the north coupled with a normal high tide. This delayed the work for a total of four days.

The SPL for nine timber piles was monitored at distances ranging from 9 meters (30 feet) to 75 meters (246 feet). The timber piles were installed with a Hydraulic Power Systems, Inc. Model 250 XL vibratory hammer with an eccentric moment of 28.7 kgm (2,500 in-lb.). The driving time for the timber fender piles ranged from one minute and twenty two second to 18 seconds. The average 10-second RMS levels at 9 to 12 meters (30 to 39 feet) ranged from 162 dB to 165 dB. **Table 6** shows the average RMS SPL for the pile driving at Naval Station Norfolk. The data have been normalized to 10 meters based on the average attenuation rates shown in **Table 9 in Section 4.1.2**.

Table 6. Average 1-second and 10-second Broadband RMS SPL (dB re 1 μPa) for Vibratory Pile-Driving Normalized to 10 meters at Naval Station Norfolk

Pile Type and Size	Distance (meters)	Average 1-second RMS SPL	Average 10-second RMS SPL
Timber Piles	10	158	158

4.1.1.4 NAVAL STATION MAYPORT, 9 THROUGH 11 JUNE 2015

In this project as well as the previous project at the Naval Station Norfolk, there was considerable variability in the levels measured for each type of pile driven. For example, during the driving of the sheet piles, the average levels ranged from 135 to 158 dB and the average levels when driving in the king piles ranged from 141 to 164 dB. The overall average for the sheet piles was 151 dB, and for the king piles the average level was 148 dB. The installation of the sheet piles tended to be louder than the installation of the king piles; this is most likely due to the differences in the overall mass of the king pile compared to the sheet piles and the difference in the length of time it took to drive a sheet pile compared to the king piles. The times to install a sheet pile ranged from 12 to 61 seconds while the king piles ranged from 6 to 152 minutes (2.5 hours). The average time to install a sheet pile was 21 seconds and the average time to install a king pile was 24 minutes. **Table 7** shows the average RMS SPL for the pile driving at the Naval Station Norfolk. The data for the king piles measured at the near position (ranging from 9 to 13 meters) has been normalized to 10 meters based on the average attenuation rates shown in **Table 9 in Section 4.1.2**. The data for the sheet piles were based on the measurements at the near position (ranging from 8 to 12 meters) has been normalized to 10 meters based on the average attenuation rates shown in **Table 9 in Section 4.1.2**.

Table 7. Average 1-second and 10-second Broadband RMS SPL (dB re 1 μPa) for Vibratory Pile-Driving Normalized to 10 meters at Naval Station Mayport

Pile Type and Size	Distance (meters)	Average 1-second RMS SPL	Average 10-second RMS SPL
Sheet pile	10	153	156
King Piles	10	148	149

4.1.1.5 JEB LITTLE CREEK NAVAL STATION, 10 THROUGH 11 SEPTEMBER 2015 ELCAS REMOVAL

The combination of shallow water and low noise levels during the extraction of the piles made it difficult to obtain data at the near location. Ideally, the measurements would have been made from a vessel 10 meters (33 feet) from the piles being pulled; however, due to safety concerns, this was not a practicable option. There was no safe way to maintain a 10-meter distance from the piles being pulled, even from the pier. On 10 September during the pile removal the time to extract a pile ranged from 1 to 4 minutes and 35 seconds. The 1-second RMS levels ranged from a low of 129 dB to 155 dB with an average level of 145 dB. The 10-second RMS levels ranged from 139 to 152 dB with an average of 145 dB. On 11 September during the pile removal, the time to extract a pile ranged from 57 seconds to 1 minute and 36 seconds. The 1-second RMS levels ranged from a low of 136 dB to 171 dB with an average level of 144 dB. The 10-second RMS levels ranged from 137 to 168 dB with an average of 145 dB. It should be noted that the 10-second maximum levels were generally lower than the 1-second maximum levels by approximately 3 dB; however, the 10-second average levels and the 1-second average levels were within 1 dB of each other. Typically the highest level measured during a vibratory pile driving event is right as the hammer starts and when it is stopped. This is a very short duration and in the 10-second averaging the impact of the higher level is averaged out by the lower levels that follow. **Table 8** shows the average RMS SPL for the pile driving at Naval Station Norfolk. The data has been normalized to 10 meters based on the average attenuation rates shown in **Table 9 in Section 4.1.2**.

Table 8. Average 1-second and 10-second Broadband RMS SPL (dB re 1 μPa) for Vibratory Pile-Driving Normalized to 10 meters at JEB Little Creek Naval Station

Pile Type and Size	Distance (meters)	Average 1-second RMS SPL	Average 10-second RMS SPL
24-inch Steel Shell	10	146	147

4.1.2 Vibratory Pile Driving Propagation and Threshold Distances

Data in **Table 3** were used to calculate the propagation rates or attenuation rates for the various pile types installed with a vibratory hammer. **Table 9** shows the results of these calculations. The acoustic spreading loss curves for each of these conditions are shown in **Figures 4 through 10**. The transmission coefficients can be used to calculate overall distances to the various threshold levels.

Table 9. Summary of Attenuation Rates for Vibratory Pile Driving Activities (dB per Log [distance])

Pile Type	Maximum		Average		Overall Average
	1-second	10-second	1-second	10-second	
Sheet pile	12.9	12.7	12.2	12.5	12.6
King pile	16.8	17.1	15.4	15.8	16.3
H-pile	33.6	28.0	31.7	34.0	31.8
Timber pile	32.7	30.4	31.1	31.9	31.5
24-inch steel shell pile	16.6	17.6	14.0	14.9	15.8
36-inch steel shell pile	24.7	24.6	24.9	24.9	24.8
48-inch steel shell pile	20.0	19.7	21.2	21.5	20.6

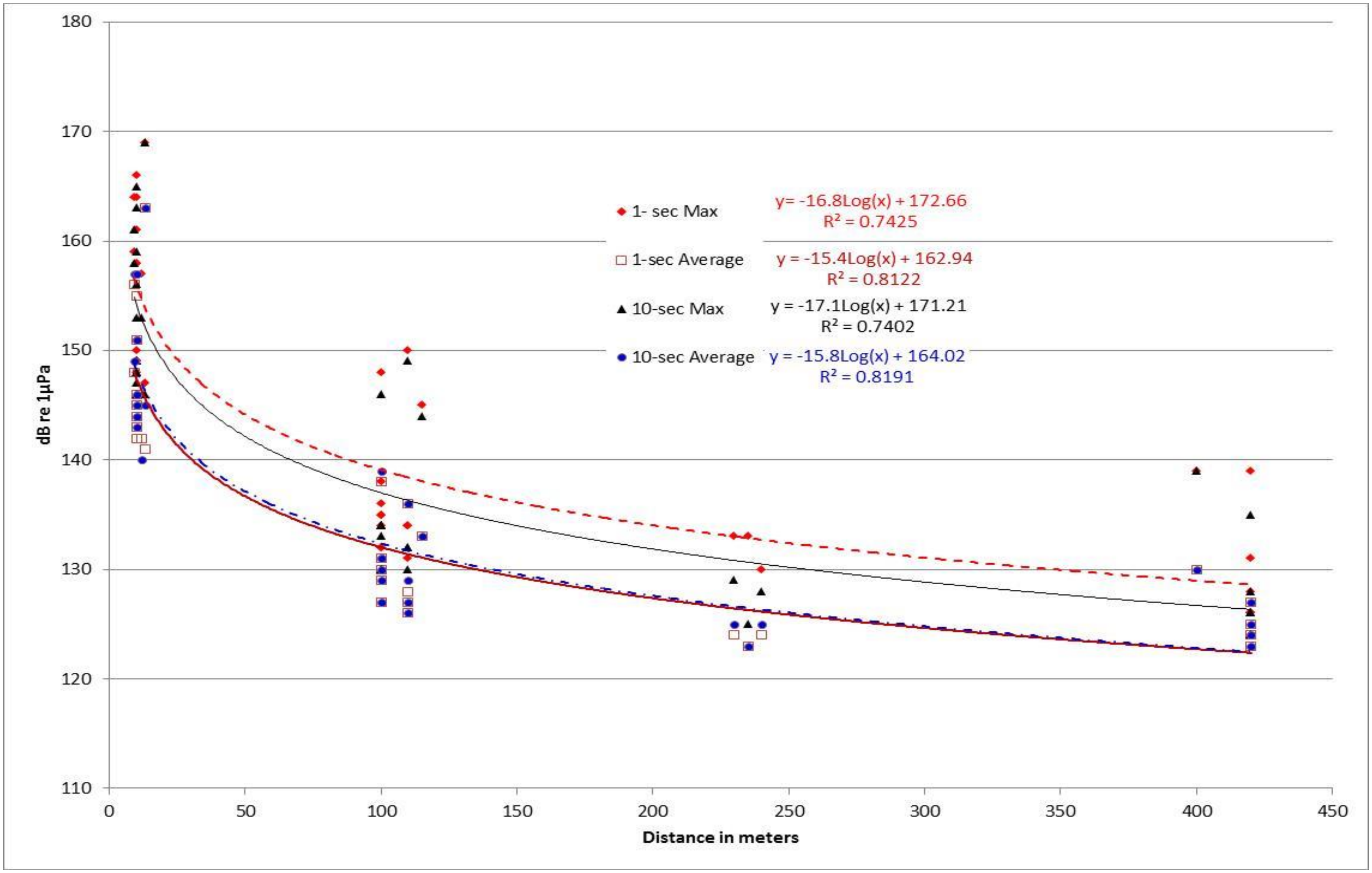

Figure 4. Acoustic Spreading Loss of RMS Levels – King Piles with Vibratory Hammer – Naval Station Mayport 9-11 June 2015

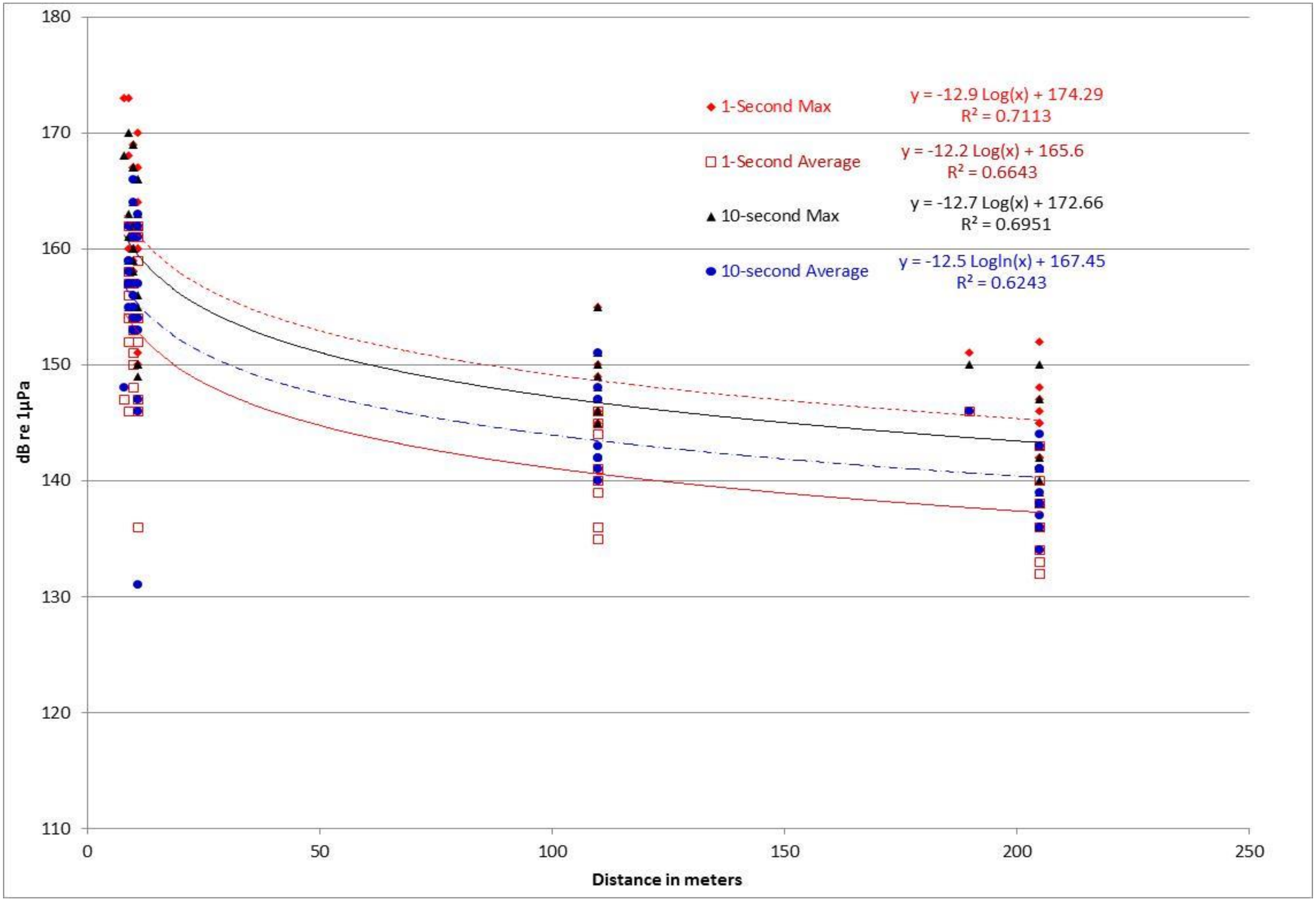

Figure 5. Acoustic Spreading Loss of RMS Levels – Sheet Piles with Vibratory Hammer– JEB Little Creek 28, 30 May 2013 and Naval Station Mayport 9–11 June 2015

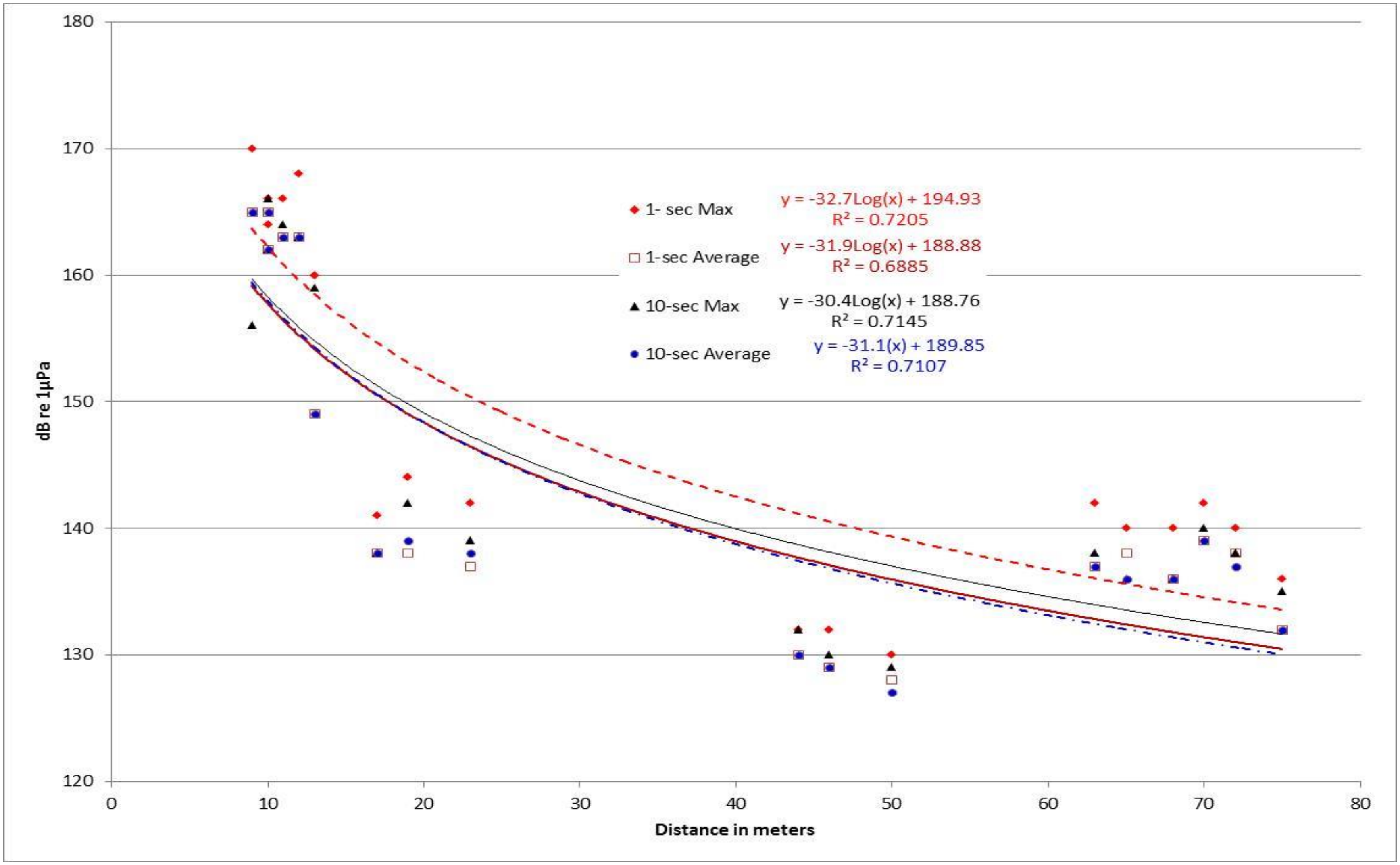

Figure 6. Acoustic Spreading Loss of RMS Levels – Timber Piles with Vibratory Hammer– Naval Station Norfolk 27 October 2014

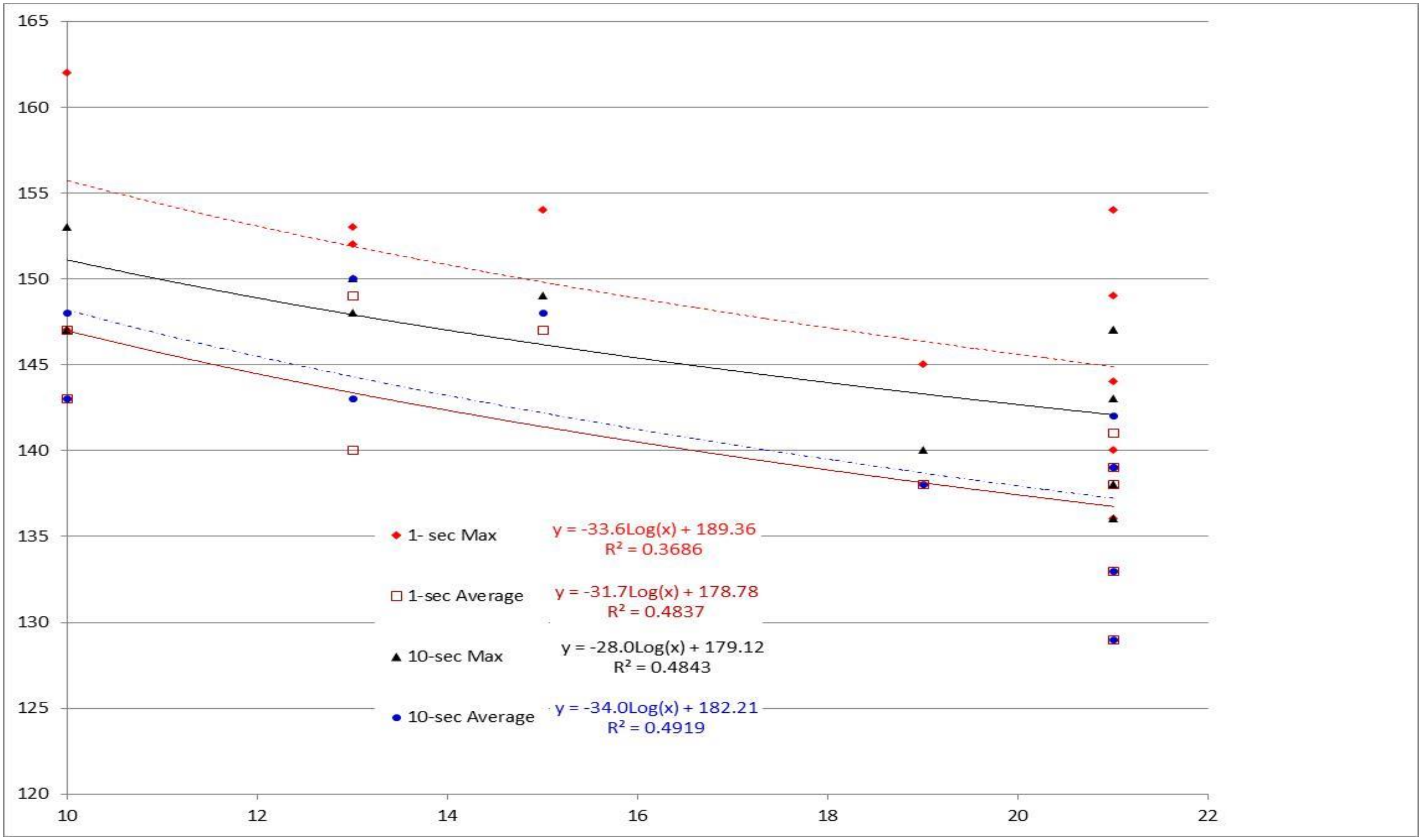

Figure 7. Acoustic Spreading Loss of RMS Levels – H-Piles (Installation and Removal) with Vibratory Hammer JEB Little Creek 28, 30 May 2013

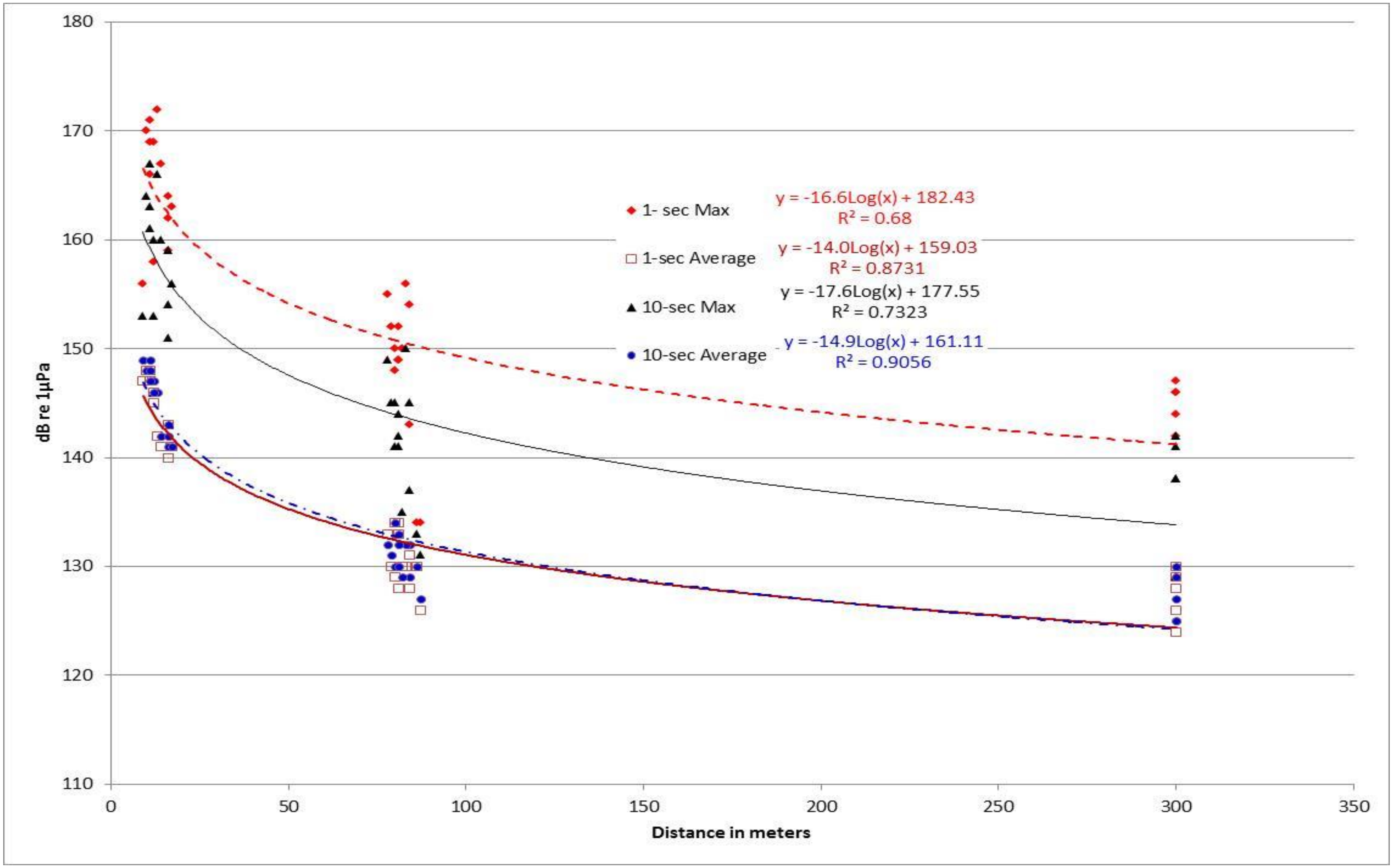

Figure 8. Acoustic Spreading Loss of RMS Levels – 24-inch Steel Shell Piles with Vibratory Hammer JEB Little Creek Naval Station 10–11 September 2015

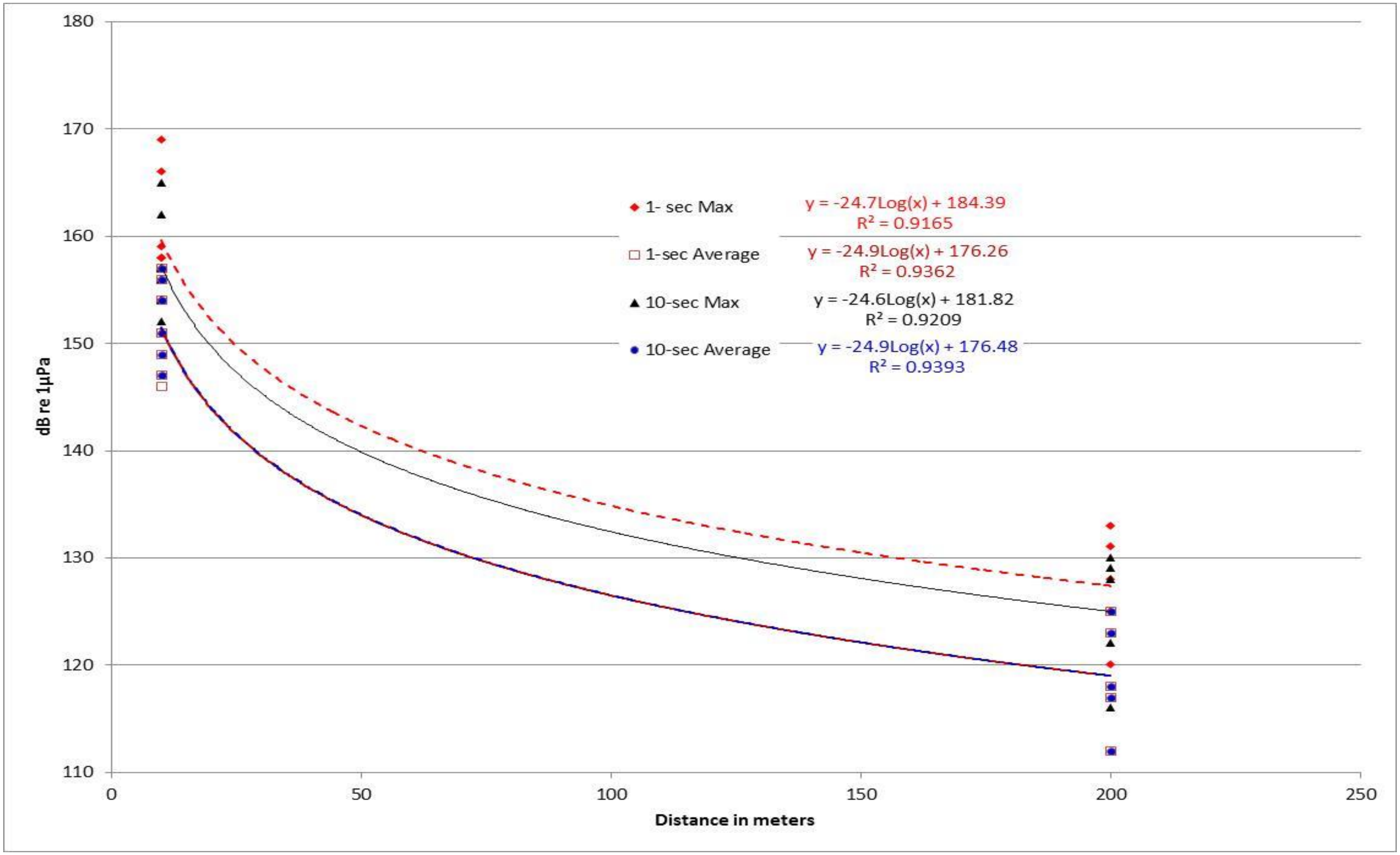

Figure 9. Acoustic Spreading Loss of RMS Levels – 36-inch Steel Shell Piles with Vibratory Hammer – Philadelphia Naval Shipyard 1–2 October 2014

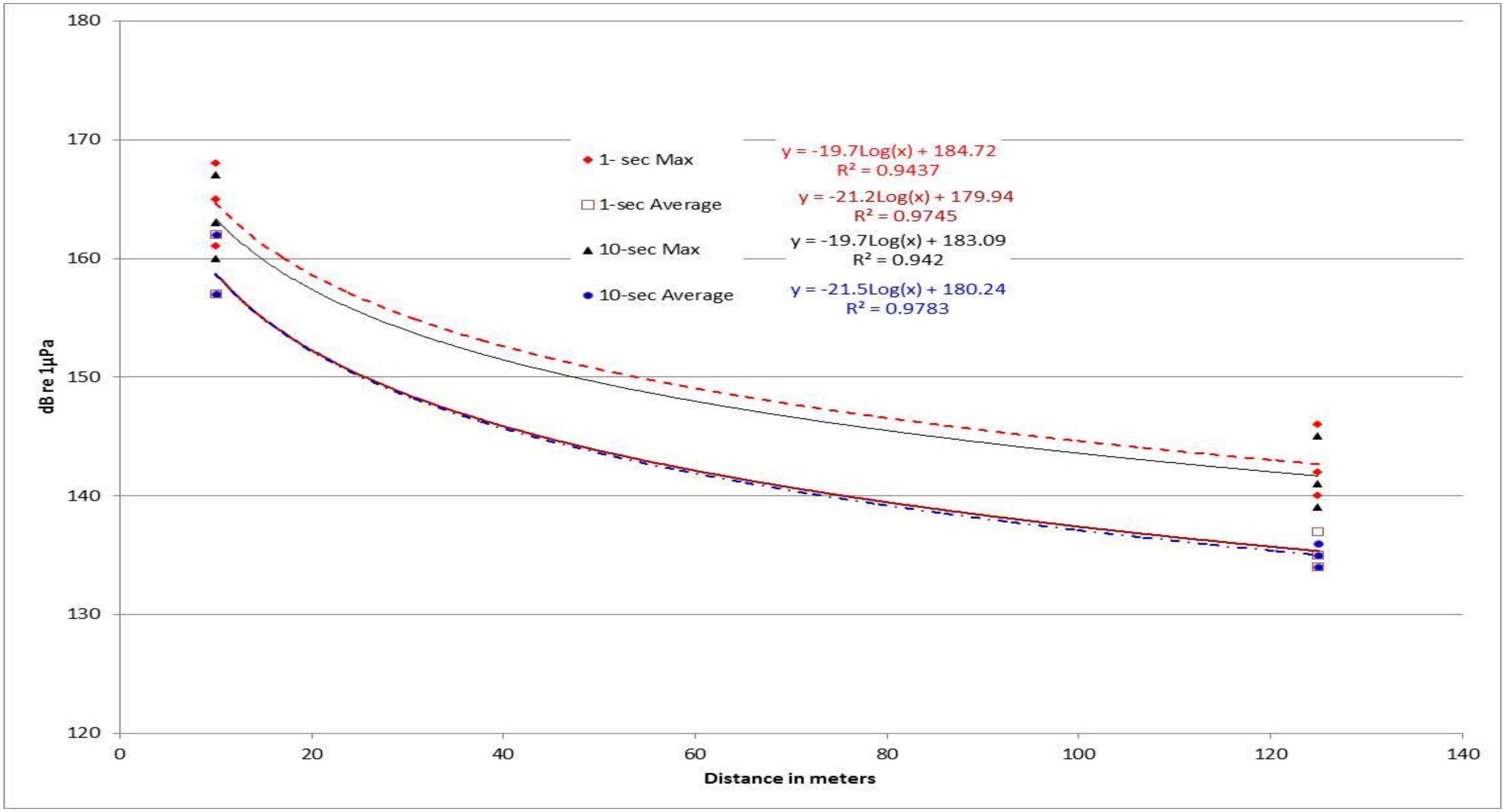

Figure 10. Acoustic Spreading Loss of RMS Levels – 48-inch Steel Shell Piles with Vibratory Hammer– Philadelphia Naval Shipyard 30 September 2014

It should be noted that the attenuation rates for the 36-inch and 48-inch steel shell piles were measured at the Philadelphia Naval Shipyard where there may have been some excess attenuation from the existing piles under the pier where the measurements were taken. This is further discussed in the lessons learned section at the end of the report. The H-piles and timber piles also have high attenuation rates; however, these seem to be close to other measurements of similar piles as shown in the Caltrans compendium of pile-driving noise.[1]

For the timber piles, the attenuation rate ranged from 22*Log_{10} to 36*Log_{10} with an average attenuation rate of 31*$Log_{10.}$ There are no data sets available to compare the vibratory installation of timber piles with other locations. However, when comparing the attenuation rate of timber piles driven with a drop hammer, the attenuation rates are similar.

4.1.3 Impact Pile Driving

There was a total of 35 impact pile-driving events monitored during the project—three 48-inch steel shell piles, nine 36-inch steel shell piles, eleven 24-inch steel shell piles, and twelve 24-inch square concrete fender piles. As with the vibratory pile driving, the sound levels generated by impact driving varied considerably from pile to pile. This section summarizes the results of the data analysis for impact pile-driving events.

There were approximately 11,460 pile strikes in total. The number of pile strikes per event ranged from 4 to 969. The durations of impact pile-driving events were short. Typical driving time for each event ranged from less than 1 minute to approximately 25 minutes.

Table 10 summarizes the distances for from the piles to the hydrophone measurement locations each impact-driving event along with the results of peak SPL, RMS SPL, SEL SPL and cSEL.

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[1] Buehler, D. Oestman, R., Reyff, J., Pommerenck, K., and Mitchell, B. Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish. November 2015.

Table 10. Statistics for Impact Pile Driving

Location	Date	Pile Type	Pile Size	Distance in Meters	Number of Blows	Peak SPL (units)		RMS SPL (units)		SEL (units)		cSEL (units)
						Average	Range	Average	Range	Average	Range	
Norfolk	5/29/2013	Concrete	24-inch	10	25	180	174-183	166	163-170	156	152-164	183
				50		158	157-159	155	153-155	147	145-148	--
				10	13	174	173-175	162	161-162	152	150-153	164
				50		158	151-159	155	154-155	146	141-148	--
Norfolk	10/21/14	Concrete	24-inch	50	19	170	169-174	158	144-162	145	135-151	162
				51	11	168	167-171	154	136-158	140	128-149	--
				52	9	167	166-167	155	152-158	137	121-148	--
				53	4	168	166-169	149	149-159	138	127-149	--
				54	17	168	167-173	157	151-160	139	123-151	163
Norfolk	10/25/14	Concrete	24-inch	9	23	184	181-186	174	171-176	164	156-165	178
				10	29	185	184-186	175	171-177	165	164-166	180
				11	30	185	184-186	176	174-177	166	165-167	181
				12	49	184	182-186	175	171-177	165	162-167	182
				13	76	184	183-185	174	170-176	164	158-166	183
Philadelphia	9/30/2014	Steel	48-inch	10	823	200	197 - 204	183	180 - 187	173	169 - 175	202
				125		178	175-182	164	159-171	153	151-159	181
				10	939	200	196 – 205	185	108 - 189	174	171 - 177	204
				125		No Data - Equipment Failure						
				10	969	203	197 -208	187	182 - 191	176	171 - 178	206
				125		180	177-185	166	163-169	155	153-157	184
Philadelphia	10/1/2014	Steel	36-inch	10	723	199	195 - 203	185	181 - 189	174	171 - 177	203
				125		174	168-180	159	152-165	148	144-153	170
				10	473	200	195 - 205	186	180 - 191	175	168 - 179	202
				125		176	167-181	161	152-167	150	144-155	176
				10	574	200	195 - 206	185	179 - 191	174	169 - 178	202
				125		174	167-179	159	152-163	148	144-151	167
				10	583	200	195 - 206	184	181 - 189	173	169 - 177	201
				125		169	163-174	154	149-159	143	139-147	--

Location	Date	Pile Type	Pile Size	Distance in Meters	Number of Blows	Peak SPL (units)		RMS SPL (units)		SEL (units)		cSEL (units)
						Average	Range	Average	Range	Average	Range	
Philadelphia	10/2/2014	Steel	36-inch	10	524	203	198 - 207	185	177 - 189	174	165 - 176	201
				10	561	200	193 - 206	183	177 - 188	172	166 - 175	200
				10	643	199	192 – 207	183	177 - 189	172	165 - 176	200
				10	560	199	192 – 204	184	178 - 189	173	165 - 178	201
				10	630	198	192 – 205	183	177 - 190	172	165 - 177	201
Little Creek	4/26/2016	Steel	24-inch	10	384	207	205-211	193	190-196	180	174-185	208
				125		192	189-194	179	173-183	167	159-172	192
				10	417	209	206-212	196	192-198	183	179-187	209
				125		194	189-196	181	179-183	168	160-172	194
				10	478	209	205-212	195	192-198	183	179-187	210
				125		194	189-196	180	175-183	168	160-171	195
				10	413	209	204-213	196	191-200	182	177-188	209
				125		191	189-194	178	175-181	165	161-169	192
Little Creek	4/27/2016	Steel	24-inch	10	50	211	207-213	198	194-199	186	182-188	203
				125		195	190-197	No Data	No Data	178	167-180	195
				500		180	173-182	167	160-168	154	148-156	171
				10	209	208	205-211	196	194-198	183	177-188	207
				10	261	208	205-212	196	194-198	184	173-187	208
				10	87	208	206-211	196	187-201	184	173-197	206
Little Creek	4/28/2016	Steel	24-inch	10	265	208	204-210	195	191-198	183	177-187	207
				500		179	176-183	167	164-170	155	143-159	179
				10	368	206	202-210	194	192-196	181	174-183	207
				500		179	177-183	167	165-170	155	147-159	180
				10	221	206	203-210	194	191-197	181	168-186	205

4.1.3.1 JEB LITTLE CREEK AND CRANEY ISLAND, 28 MAY THROUGH 30 MAY 2013

Monitoring was also completed on one concrete pile driven at two different times at Craney Island. The pile was being driven to check the bearing and was struck 25 blows the first time and was struck 14 blows the second time. The peak, RMS, SEL, and Cumulative SEL were recorded at two locations, 10 meters (33 feet) and approximately 50 meters (164 feet). The piles were driven using an ICE 220 diesel impact hammer. These levels would not necessarily match or be reflective be of the typical levels measured for the driving of a typical concrete pile due to the short duration of the drives. **Table 11** shows the average Maximum Peak, average RMS and average 1-second SELs as measured at Craney Island.

Table 11. Average Maximum Peak, RMS SPL, SEL SPL for Impact Pile-Driving Measured at 10 meters at JEB Little Creek Naval Station

Pile Type and Size	Distance (meters)	Average Maximum Peak SPL	Average RMS SPL	Average SEL SPL
24-inch square Concrete	10	179	164	154

4.1.3.2 PHILADELPHIA NAVAL SHIPYARD, 30 SEPTEMBER THROUGH 2 OCTOBER 2014

Measurements were made during the impact driving of three 48-inch steel shell piles and nine 36-inch steel shell piles. During the impact driving, an APE D70-52 diesel impact hammer an energy rating between 117.21 kNm (1,041,864 in-lb) and 234.42 kNm (2,083,728 in-lb) was used for all the piles. There were between 823 and 969 pile strikes used to drive the 48-inch piles and between 473 and 630 pile strikes used to drive the 36-inch piles. The SPLs measured at 10 meters (33 feet) seemed to follow what would be anticipated for these pile types and sizes. The maximum peak levels ranged from 204 to 208 dB for the 48-inch piles and the 36-inch piles ranged from 203 to 207 dB. These levels could be reduced with the usage of an attenuation system, such as a bubble ring around the piles driven. **Table 12** shows the average Maximum Peak, average RMS and average 1-second SELs for each size pile as measured at the Philadelphia Naval Shipyard.

Table 12. Average Maximum Peak, RMS SPL, SEL SPL for Impact Pile-Driving Measured at 10 meters at Philadelphia Naval Shipyard

Pile Type and Size	Distance (meters)	Average Maximum Peak SPL	Average RMS SPL	Average SEL SPL
36-inch Steel Shell	10	205	184	173
48-inch Steel Shell	10	206	185	174

4.1.3.3 NAVAL STATION NORFOLK, 21 THROUGH 27 OCTOBER 2014

During this project there was a delay during the measurements due to an extremely high tide that flooded the docks where the work was supposed to occur. This high tide was caused by a combination of factors, including a strong storm surge from the north coupled with a normal high tide. This delayed the work for a total of four days. The type of fender piles measured were 24-inch square concrete piles driven in by a Vulcan 010 Drop hammer with an energy rating of 44.1 kilojoules (390,000 in-lb). There were very few pile strikes used to set the piles, they ranged from 4 pile strikes to 76 pile strikes. The average RMS levels measured at 9 to 13 meters (30 to 43 feet) ranged from 164 to 166 dB. **Table 13** shows the average Maximum Peak, average RMS and average one-second SELs either measured at 10 meters or the data was normalized to 10 meters.

Table 13. Average Maximum Peak, RMS SPL, SEL SPL for Impact Pile-Driving at 10 meters at Naval station Norfolk

Pile Type and Size	Distance (meters)	Average Maximum Peak SPL	Average RMS SPL	Average SEL SPL
24-inch square Concrete	10	189	176	163

Upon analyzing the data in detail, an excess amount of sound attenuation was present, particularly when compared with values obtained from similar projects in other locations. For example, in Choctawhatchee Bay, Florida, impact pile driving attenuation rates for 24-inch (61-centimeter) solid square concrete piles were approximately between $20*Log_{10}$ and $22*Log_{10}$ (unpublished data). On this project, the attenuation rates ranged from $23*Log_{10}$ to $27*Log_{10}$. The attenuation rates measured were slightly higher than expected and could be attributed two likely factors: hammer type and the fact that the piles were shorter and non-bearing, which means that they were not struck as hard as other projects. Typically, drop hammers have a lower energy rating than diesel impact hammers, and this could result in a higher attenuation rate due to less energy emitted through the pile. Secondly, these piles were being tapped down to a tip elevation, not to a set-bearing load, and the piles were shorter, which would mean less pile to radiate noise.

4.1.3.4 JEB LITTLE CREEK NAVAL STATION, 26 THROUGH 28 APRIL 2016 ELCAS CONSTRUCTION

The measured noise levels were higher than typically measured for 24-inch steel piles; typically the peak SPL for a 24-inch steel pile would be approximately 208 dB. The difference between the different metrics, the peak and RMS and the RMS and the SEL, were in the range that would be measured. The calculated propagation rate is similar to that measured for this type pile in other locations. Overall, other than the slightly higher levels measured, these results are what would be typically expected when driving an unattenuated 24-inch steel shell pile. **Table 14** shows the average Maximum Peak, average RMS and average one-second SELs for each size pile as measured at 10 meters during the pile driving for the ELCAS at the

Table 14. Average Maximum Peak, RMS SPL, SEL SPL for Impact Pile-Driving Measured at 10 meters at JEB Little Creek Naval Station

Pile Type and Size	Distance (meters)	Average Maximum Peak SPL	Average RMS SPL	Average SEL SPL
24-inch Steel Shell	10	211	195	184

4.1.4 Impact Pile Driving Propagation and Threshold Distances

Data in **Table 15** are presented to chart relationships of peak SPLs, RMS SPLs, and SELs for impact driving the various pile types. The acoustic spreading loss curves for each of these conditions are shown in **Figures 11 through 14**. The peak spreading loss curves are based on the maximum peak level measured during each event. The RMS and SEL curves are based on the average levels measured during each event. The spread between the maximum pile strike and the average pile strike was usually within ±3 dB. The transmission coefficients can then be used to calculate distances to the various threshold levels. Again, data for 36-inch and 48-inch diameter piles may have some excess attenuation due to conditions at the measurement sites.

Table 15. Summary of Attenuation Rates for Impact Pile-Driving Activities (dB per Log [distance])

Pile Type	Type of Pile Driving	Average Peak	Average RMS	Average SEL
Concrete piles	Pneumatic impact	24.2	24.2	28.7
24-inch steel Shell Pile	Diesel impact	15.1	16.0	15.8
36-inch steel Shell Pile	Diesel impact	24.1	23.6	23.6
48-inch steel Shell Pile	Diesel impact	20.0	18.2	18.5

For the concrete pile it must be noted that these were short fender piles and as such they were only driven to a set tip elevation not to any bearing depth. The reason this is mentioned is because it appeared that an excess amount of sound attenuation was present, particularly when compared with values obtained from similar projects in other locations. For example, in Choctawhatchee Bay, Florida, impact pile driving attenuation rates for 61-centimeter (24-inch) solid square concrete piles were approximately between 20*Log_{10} and 22*Log_{10} (unpublished data). On this project, the attenuation rates ranged from 23*Log_{10} to 27*Log_{10}. The attenuation rates measured were slightly higher than expected and could be attributed two likely factors: hammer type and the fact that the piles were shorter and non-bearing, which means that they were not struck as hard as other projects. Typically, drop hammers have a lower energy rating than diesel impact hammers, and this could result in a higher attenuation rate due to less energy emitted through the pile. Secondly, these piles were being tapped down to a tip elevation, not to a set-bearing load, and the piles were shorter, which would mean less pile to radiate noise.

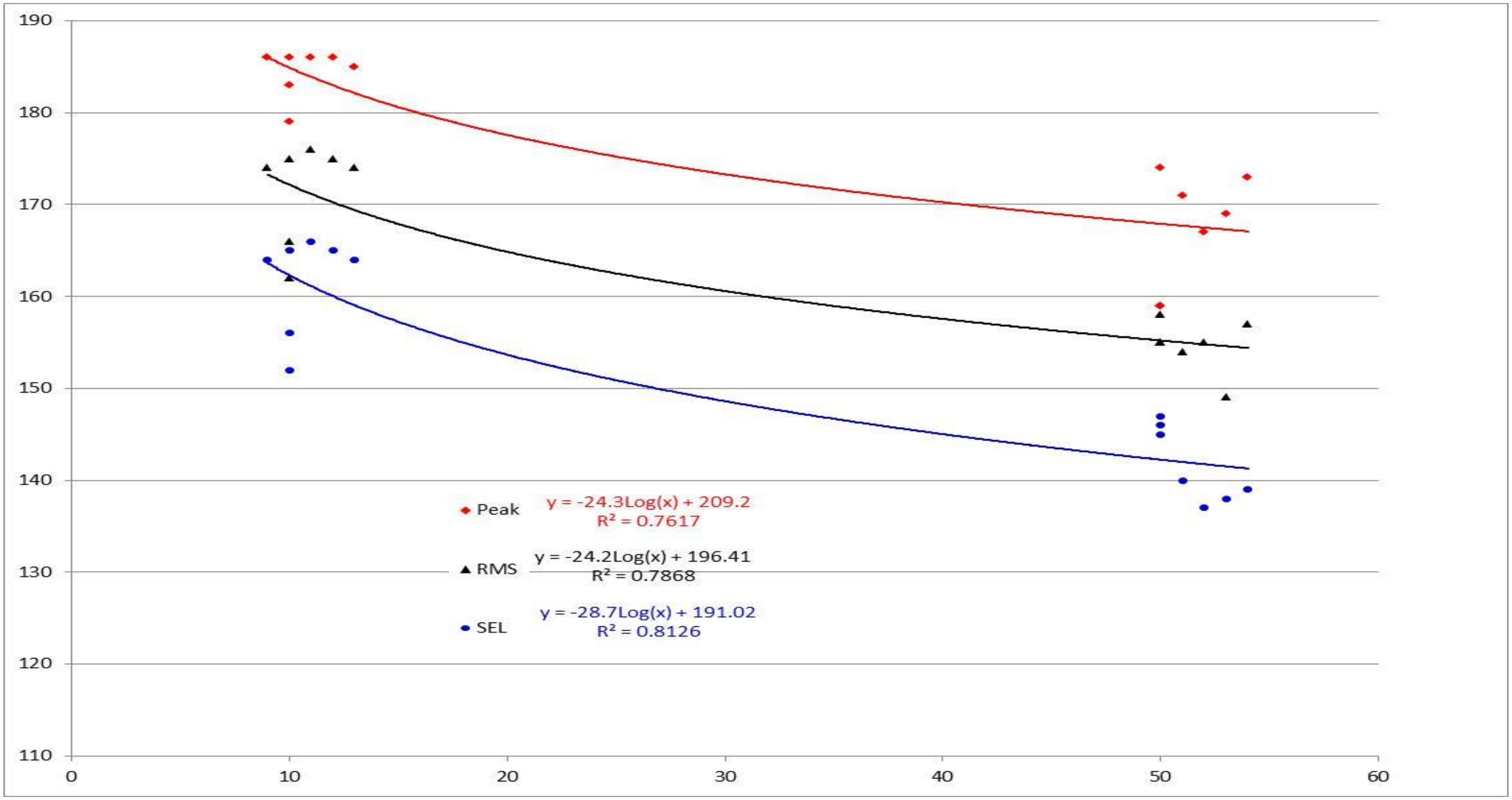

Figure 11. Acoustic Spreading Loss of RMS Levels – 24-inch Concrete Piles with Impact Hammer Craney Island 29 May 2013 and Naval Station Mayport 9-11 June 2015

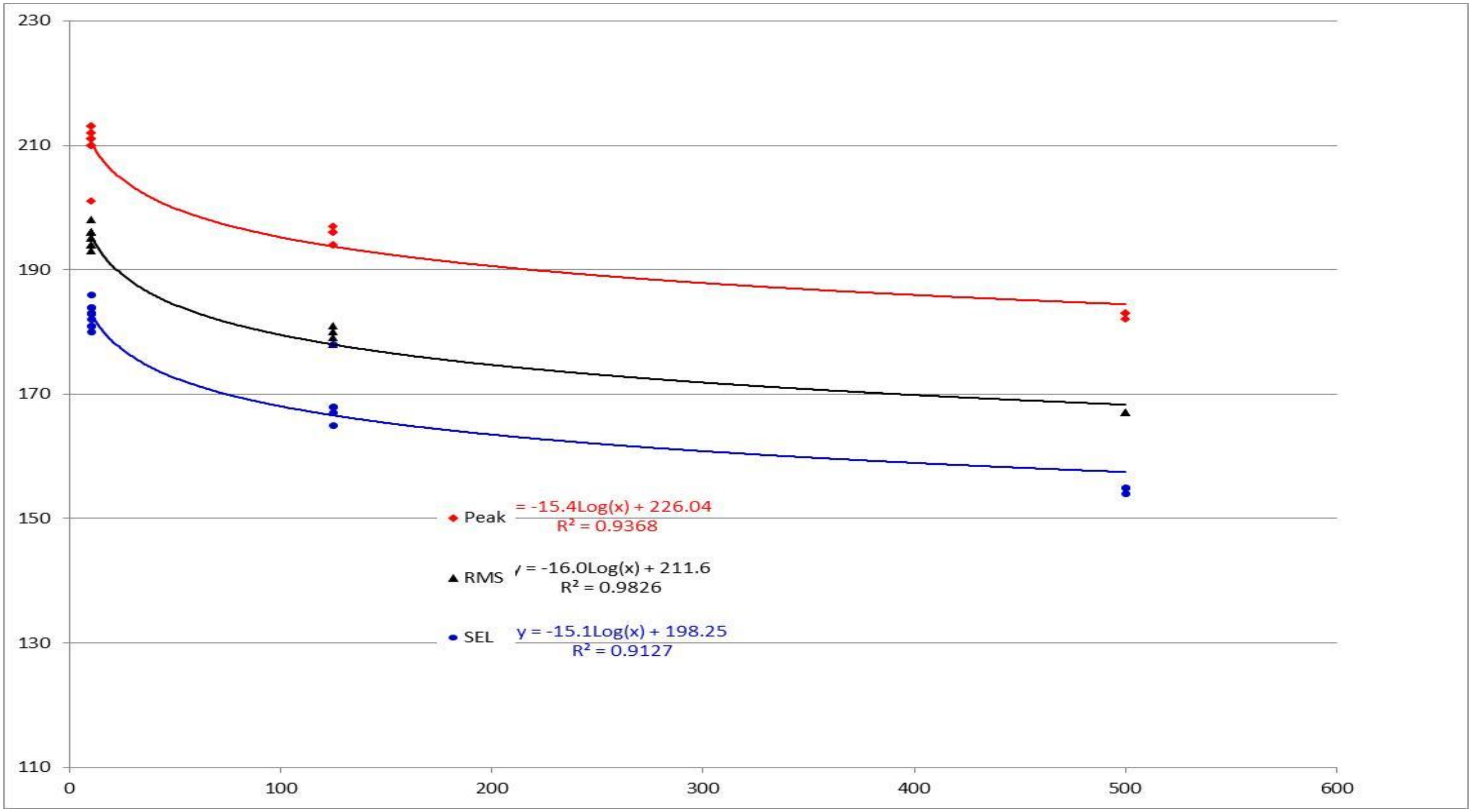

Figure 12. Acoustic Spreading Loss of RMS Levels – 24-inch Steel Shell Piles with Impact Hammer JEB Little Creek Naval Station 26–28 April 2016

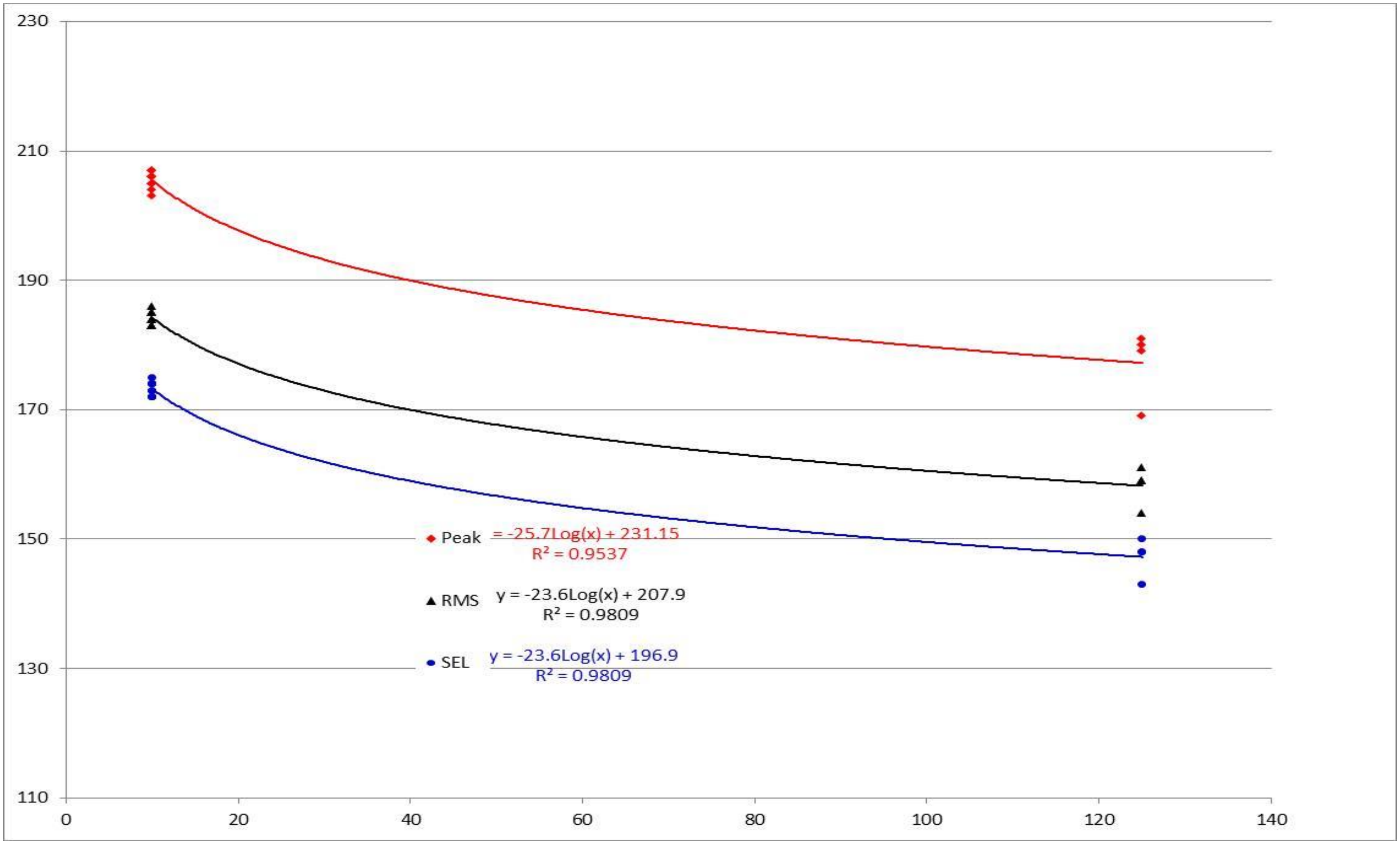

Figure 13. Acoustic Spreading Loss of RMS Levels – 36-inch Steel Shell Piles with Impact Hammer Philadelphia Naval Shipyard 1–2 October 2014

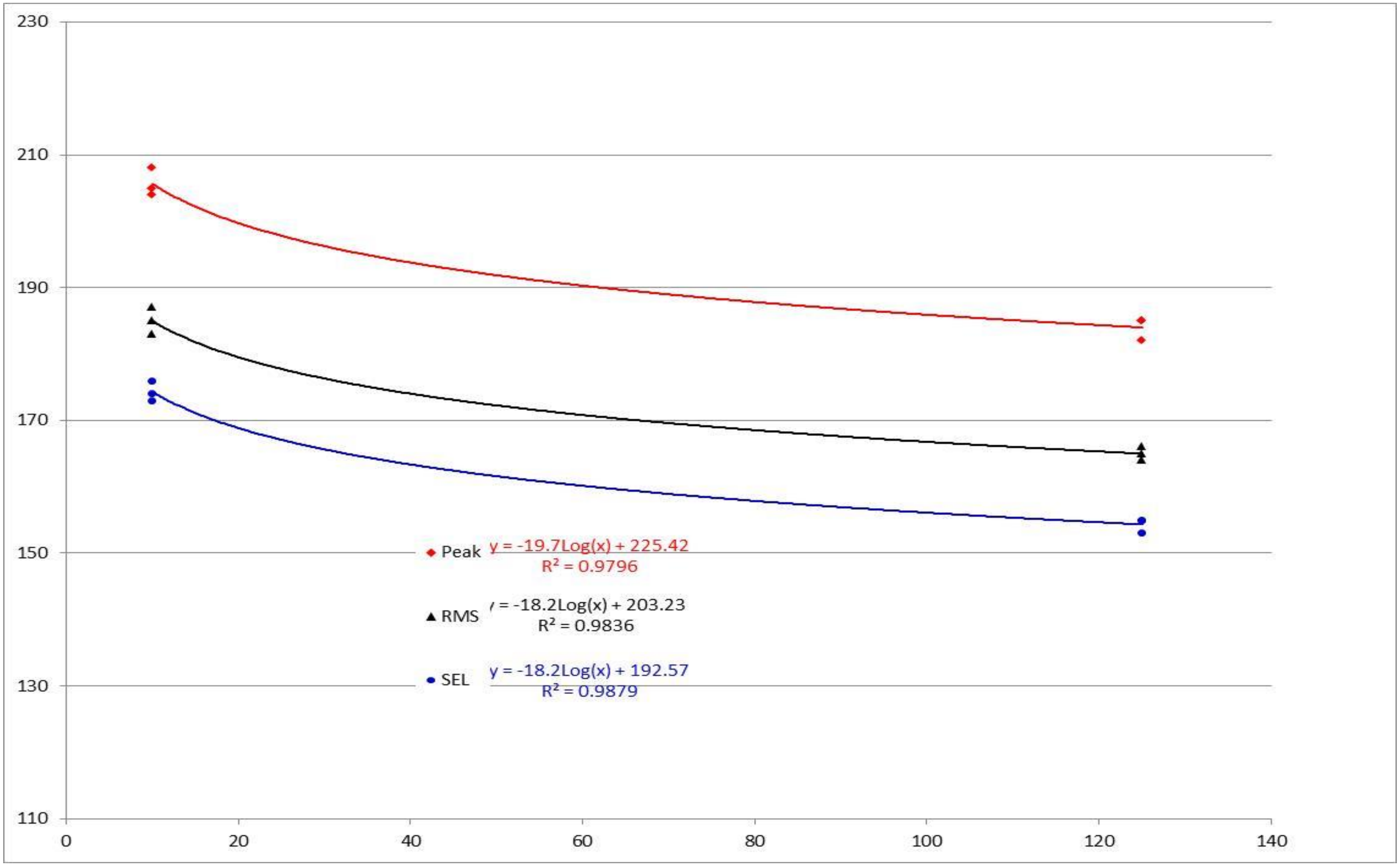

Figure 14. Acoustic Spreading Loss of RMS Levels – 48-inch Steel Shell Piles with Impact Hammer Philadelphia Naval Shipyard 30 September 2014

Upon analyzing the data from the Philadelphia Naval Shipyard for the 36-inch and 48-inch steel piles in detail, an excess amount of sound attenuation was present, particularly when compared with values obtained from similar projects in other locations. For example, in San Francisco Bay, impact pile driving attenuation rates for 48-inch and 36-inch piles are approximately between $12*Log_{10}$ and $17*Log_{10}$ (unpublished data). On this project, the attenuation rates ranged from $18*Log_{10}$ to $23*Log_{10}$. These are extremely high attenuation rates that could only result from a couple of factors; very shallow water and/or obstructions in the water. Because this is a working dock with some of the largest naval ships present, the water is not deemed particularly shallow. After a thorough review of the site, there were an extremely high number of existing piles present (approximately 34 wood piles in each pile row and approximately 105 rows of piles spaced approximately 10 feet apart under the existing Pier 4) that could have caused the high rates attenuation.

4.1.5 Background Sound Levels

Background noise levels were measured during all pile-driving events. These included anthropogenic noise and weather-influenced wave noise. More specifically, anthropogenic noise resulted from transient vessel traffic and local work-site compressors and generators. **Table 16** details a “snapshot” of these background levels.

Table 16. Background levels

Date	Location	Distance (meters)	1-second RMS		10-second RMS	
			Average	Range	Average	Range
28 June 2013	JEB Little Creek	10	110	107-128	110	108-119
29 June 2013	Craney Island	10	117	110-132	118	115-124
30 June 2013	JEB Little Creek	10	113	108-127	113	110-120
30 September 2014	Philadelphia Naval Shipyard	10	120	118-124	120	119-122
01 October 2014		10	121	117-129	121	120-125
02 October 2014		10	111	106-137	112	107-131
25 October 2014	Naval Station Norfolk	10	123	116-140	124	119-132
27 October 2014		10	122	117-135	123	118-131
09 June 2015	Naval Station Mayport	10	131	125-139	132	130-134
		200	120	119-126	120	119-121
10 June 2015		10	123	120-128	123	121-127
11 June 2015		10	128	121-134	129	126-131
10 September 2015	JEB Little Creek Naval Station	10	119	112-144	121	113-135
11 September 2015		10	131	118-146	133	127-138
26 April 2016	JEB Little Creek Naval Station	10	114	103-128	116	105-123
27 April 2016		10	128	109-148	128	111-143
28 April 2016		10	144	139-149	143	136-150

The background levels varied a great deal depending on construction and operational activities and weather conditions. As an example, at Naval Station Mayport experienced a 17- to 22-dB difference in the average RMS level between 9 June and the next two days (10 and 11 June). This difference was due to an increase in Navy vessel activities and other work occurring at the project site on 10 and 11 June. At JEB Little Creek between 26 and 28 April 2016, the difference in the average background levels varied from 116 to 143 dB. This increase can be attributed to progressively worsening weather conditions. On 26 April, the winds were approximately 4 knots (5 miles per hour), and by 28 April the winds increased to in excess of 17 knots (approximately 20 miles per hour). The increase caused the waves to develop from small wavelets with no breaking waves to moderate, breaking waves 4 to 8 feet in height. Elevated underwater noise levels resulted due to waves breaking around the existing piles. The same was true during the previous measurements at JEB Little Creek Naval Station taken on 10 and 11 September 2015. The conditions were slightly worse on the first day, but the conditions on the second day never attained the levels monitored on 28 April 2015.

4.1.6 Summary of Airborne Sound Monitoring Data

Airborne sound levels were measured and analyzed as un-weighted and A-weighted levels, and both are reported (**Appendix C**). Airborne sound levels were measured in 1-minute and at times 1-second intervals throughout each workday, typically approximately 15 meters (50 feet) from the pile-driving activity; it's important to note that there were occasions when it was not safe to place the SLM at the 15-meter (50-foot) position.

Airborne monitoring microphones were affected by pile-driving noise, other construction activities, and other noise sources including patrol boats, monitoring boats, and intermittent sources such as voices and radio communications. The levels of these cumulative noises and their frequencies of occurrence depended upon the proximity to each of the monitoring microphones to the various sound sources. The measurements made at approximately 15 meters (50 feet) from the pile-driving activity, logically provided the best indication of local pile-driving levels. Crane activity and compressors also produced considerable noise.

While vibratory driving was audible from the construction barge to humans, the low-frequency contribution from engines and other construction equipment may have contributed significantly to the un-weighted sound levels that were measured prior, during, and after pile driving. This compromises the use of these data for predicting attenuation of the vibratory sound levels, since the competing sources are at different distances than the vibratory pile-driving sounds.

4.1.6.1 JEB LITTLE CREEK AND CRANEY ISLAND, 28 MAY THROUGH 30 MAY 2013

Airborne measurements were also made at a fixed location from the pile driving. On 28 and 30 May, the distance to the pile driving ranged from 23 to 35 meters (75 to 115 feet). The measurement site was the closet safe secure location to place a sound level meter. A Larson Davis 820 sound level meter was used to measure the airborne noise from the pile driving. Measurements were made during the installation of sheet piles, H-piles and 24-inch Concrete piles. Measurements were also made during the removal of H-piles. **Table 17** summarizes the maximum L_{eq} and L_{max} during the pile driving and the range of the L_{eq} and L_{max} during the period when no pile driving occurred.

Table 17. Summary of Airborne measurements made at JEB Little Creek and Craney Island 28 through 30 May 2013

Date	Location	Distance (meters)	Type of Pile	Lmax, dBA	
				Leq	Lmax
28 May 2013	JEB Little Creek	15	Sheet Pile	82	88
			Removal of H-pile	76	82
			Installing H-Pile	74	81
			No work	55-79	62-94
29 May 2013	Craney Island	15	24-inch square Concrete	77	92
			No Work	57-92	63-102
30 May 20013	JEB Little Creek	27-30	Sheet Pile	95	100
			Removal of H-pile	81	85
			Installing H-Pile	74	80
			No work	57-78	60-94

4.1.6.2 PHILADELPHIA NAVAL SHIPYARD, 30 SEPTEMBER THROUGH 2 OCTOBER 2014

No measurements were made on 30 September 2014 due to safety concerns of the contractor, there was too much activity on the pier were the SLM need to be placed. The contractor had materials being delivered and there were numerous operations occurring up and down the pier. On 1 and 2 October 2014, measurements were made at approximately 15 meters (50 feet) from the pile-driving activities. During the impact driving of the 36-inch steel shell piles, the average L_{max} was 113 dBA and the average Leq was 103 dBA during the driving and outside the driving windows the L_{max} was ranged from 73 to 108 dBA and the L_{eq} ranged from 69 to 98 dBA. During the vibratory pile driving the average L_{max} was 98 dBA and the average L_{eq} was 92 dBA.

4.1.6.3 NAVAL STATION NORFOLK, 21 THROUGH 27 OCTOBER 2014

During the driving of the concrete fender piles on 21 and 25 October 2014, measurements were made at 15 meters (50 feet) from the pile driving. During the impact driving of the 24-inch square concrete piles, the average L_{max} was 101 dBA and the average L_{eq} was 93 dBA during the driving and outside the driving windows the L_{max} was ranged from 72 to 100 dBA and the L_{eq} ranged from 67 to 88 dBA. On 27 October 2014, timber fender piles were installed using a vibratory pile driver. During the vibratory pile driving, the average L_{max} was 88 dBA and the average L_{eq} was 85 dBA during the driving and outside the driving windows the L_{max} was ranged from 76 to 85 dBA and the L_{eq} ranged from 66 to 81 dBA.

4.1.6.4 NAVAL STATION MAYPORT 9 THROUGH 11 JUNE 2015

Airborne measurements were made during the vibratory pile driving of the king piles on 9 June 2015. During the vibratory driving of the 48-inch king piles, the average L_{max} was 87 dBA and the average L_{eq} was 85 dBA during the driving. Measurements were not made outside the pile driving time frame due to moving the equipment and getting it set to maintain the 15-meter (50-foot) distance to all the piles during the driving. Measurements were no made during the installation of the sheet piles due to their being no safe place to set the SLM. On the days the sheets were being installed there was a lot of movement of equipment on the dock that precluded safely setting up the SLM.

4.1.6.5 JEB LITTLE CREEK NAVAL STATION, 10 THROUGH 11 SEPTEMBER 2015 ELCAS REMOVAL

There was no safe way to maintain a set 15-meter (50-foot) distance from the pile driving activities. There was no convenient location on the end of the decking to place the airborne system where it was not in the way and able to measure the noise primarily from the vibratory extractor. There were three separate noise-generating components from this operation—the crane, the power plant that provided power to the vibratory extractor, and the actual vibratory extractor. The power plant was in a fixed position, and the crane, while it did not change position, did rotate, causing the primary noise (from the engine) as it rotated. The vibratory extractor was moved from pile to pile; there were times when the power plant was closer to the measurement site, and there were times that the vibratory extractor was closer. This made it difficult to separate the noise of the vibratory extractor from the other sources. On 11 September, the wind was blowing from the north at approximately 11 to 16 knots with gusts up to 18 knots (33 kilometers per hour) and this caused an increase in the low-end frequencies.

The A-weighted data show an approximate 10-dB increase between the background levels and the times that the pile was being extracted, while the Z-weighted frequencies show a 0 to 3 dB difference. As the day progressed, the wind speeds increased so that on the last pile removed it was not possible to detect the noise of the activity based on the Z-weighted data.

4.1.6.6 JEB LITTLE CREEK NAVAL STATION, 26 THROUGH 28 APRIL 2016 ELCAS CONSTRUCTION

During the driving of the 24-inch steel shell piles for the ELCAS construction, measurements were made only on 26 April 2016 and for part of one pile on 27 April 2014 due to high winds. During the impact driving of the 24-inch steel shell piles, the average L_{max} was 103 dBA and the average Le_q was 99 dBA. During the driving and outside the driving windows, the L_{max} ranged from 75 to 100 dBA and the L_{eq} ranged from 73 to 96 dBA. During the vibratory pile driving, the average L_{max} was 98 dBA and the average L_{eq} was 92 dBA.

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5. Discussion

5.1 Lessons Learned

There were a number of lessons learned from this study. The following is a list of challenges and how they were corrected:

- At the Philadelphia Naval Shipyard, some distant measurements had an extremely high attenuation rate. It was discovered after analyzing the data that the existing dock had several rows of wooden piles under the dock where the work was occurring, which shielded the distant hydrophone, causing the high attenuation rate. After this project, a vessel was made available to allow clean line of sight for future measurements.
- During the monitoring at the Philadelphia Naval Shipyard, researchers lost some data when a hydrophone was swept behind a pier, causing the measurement data to be invalid. This was corrected on later projects by having a better pre-measurement discussion on what to be aware of. While this helped, multiple measurements are necessary to be fully aware when the data on a meter appears inaccurate and for researchers to determine how to rectify the problem.
- On 1 October 2014, researchers attempted to measure out to the estimated Marine Mammal Level B Harassment zone, approximately 1.1 kilometer (3,610 feet).This distance was calculated using the data measured on 30 September 2014 and assuming a standard attenuation rate of 15 Log. The researcher did not successfully collect any useful data at their location and did not move to a closer point. Shielding may have occurred from a ship moored at the pier between the pile driving and the measurement site, or there may have been an area that was not dredged between the measurement site and the pile driving.
- Damage occurred to key pieces of equipment transported to monitor construction of the ELCAS at JEB Little Creek, Norfolk, Virginia on 26, 27, and 28 April 2016. The power supply in the autonomous unit was damaged beyond repair, and it appeared that someone mishandled the SLMs along with the autonomous unit causing the programs to be reset. Based on the damage to the equipment, most likely due to rough handling by either airline baggage personal or TSA, all future equipment will be shipped either by FedEx or UPS. Backup systems are also shipped in case of shipping damage to the primary systems.

5.2 General Discussion

In general terms, underwater pile-driving noise is defined by the size and type of hammer, the size and type of pile, the depth of the water and the composition of the sediment that the pile is being driven in. There are many different types of hammers used in pile driving which can be broken down into two basic types; impact and vibratory. For impact hammers there are diesel impact hammers, hydraulic impact hammers and drop hammers, which each have different sound signatures when driving piles. With vibratory hammers the primary difference is in the size of the hammer. Typically one can expect the same energy transfer, or noise generation, between similar hammers and pile types regardless to where the pile is being driven. The primary difference in the noise generated in the water for similar piles and hammers is the depth of water and the sediment type and composition where the pile is being driven.

There is a growing database of underwater noise levels measured during pile driving operations being compiled and maintained by the California Department of Transportation[2] (compendium). **Table 18** details typical underwater sound pressure levels resulting from pile driving measured in California, Oregon, Washington, Nebraska, Idaho, Hawaii, and Alaska as shown in the compendium and compares them to the measurements made for this project

Table 18. Comparison of Compiled Underwater Pile Driving Data and Measurements Made at 10 meters during this Project from 28 May 2013 through 28 April 2016

Pile type	Hammer Type	Data from Compendium			Measured Data for Navy		
		Peak	RMS	SEL	Peak	RMS	SEL
H-Piles	Vibratory	165	150	150	NR	147	NR
24-inch Concrete	Drop	184[1]	173[1]	ND	189	176	163
Sheet Piles	Vibratory	177	163	163	NR	154	NR
Timber	Vibratory	ND	ND	ND	NR	158	NR
24-inch Steel Shell	Vibratory	184	ND	159	NR	146	145
	Diesel Impact	210	194	178	211	195	184
36-inch Steel Shell	Vibratory	185	175	175	184	152	151
	Diesel Impact	210	193	183	205	184	173
48-inch Steel Shell	Vibratory	ND	ND	ND	NR	159	NR
	Diesel Impact	205	195	185	206	185	174

ND – No Data
NR – Not Reported
[1] 16-inch square concrete pile

The underwater noise measurements from the various locations, pile types, and hammer types are not significantly different than those detailed in the compendium. The main differences noted are in the vibratory data for the sheet piles, the 24-inch steel shell piles and the 36-inch steel shell piles. The data in the compendium shows the RMS value to be 9 to 21 dB higher than measured during this project. The main problem with this type of comparison is that that the data measured is a compilation of many pile-driving events (33 sheet piles, 24 steel shell piles, and 7 H-piles) and is being compared to limited data compiled in the compendium. The primary reason for this is that vibratory pile driving is not routinely monitored in most locations along the west coast. Note that the differences in the data for the impact driving of the steel shell piles from the compendium relates fairly close to the measurements made for the steel shell piles in this project. What **Table 18** shows, in part, is that there is a need to gather more data from different types of pile-driving events whenever possible so better predictions can be made when assessing project impacts to fish and marine mammals.

[2] CALTRANS (California Department of Transportation). 2015. *Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish* Prepared by ICF Jones & Stokes and Illingworth and Rodkin. Sacramento, CA. November 2015.

There will be variability in pulsed-RMS measurements since the RMS level is a function of the pulse duration (in seconds). The characteristics of the sound emanating from the pile along with the contribution of sounds from the substrate can substantially vary the pulse duration. Longer duration pulses can result in lower sound levels, while having similar energy levels (i.e., SEL).

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6. Glossary

A-Weighted – The sound pressure level in decibels as measured on a sound level meter using the A-weighting filter network. The A-weighting filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise.

Ambient sound – Normal background noise in the environment that has no distinguishable sources.

Ambient sound level – The background sound pressure level at a given location, normally specified as a reference level to study a new intrusive sound source.

Amplitude – The maximum deviation between the sound pressure and the ambient pressure.

Background level – Similar to ambient sound level with the exception that is a composite of all sound measured during the construction period minus the pile removal.

C-Weighted – C-Weighting is a standard weighting of the audible frequencies commonly used for the measurement of Peak Sound Pressure level. Measurements made using C-weighting are usually shown with dB(C) to show that the information is C-weighted decibels.

Cumulative sound exposure level (cSEL) – In an evaluation of pile-driving impacts, it may be necessary to estimate the cumulative SEL associated with a series of pile-strike events. cSEL can be estimated from the single-strike SEL and the number of strikes that likely would be required to place the pile at its final depth by using the following equation:

$$cSEL = SEL_{\text{single strike}} + 10*\log(\#\text{ of pile strikes})$$

Decibel (dB) – A customary scale most commonly used for reporting levels of sound. A difference of 10 dB corresponds to a factor of 10 in sound power. A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for water is 1 microPascal, and for air it is 20 microPascals (the threshold of healthy human auditory sensitivity).

ELCAS – Elevated Causeway.

Fast, Slow, and Impulse – Most sound level meters have two conventional time weightings, F=Fast and S = Slow with time constants of 125 milliseconds (ms) and 1,000 ms, respectively. Some also have I = Impulse time weighting, which is a quasi-peak detection characteristic with rapid rise time (35 ms) and a much slower 1.5-second decay.

- F = 125 ms up and down
- S = 1 second up and down
- I = 35 ms while the signal level is increasing or 1,500 ms while the signal level is decreasing.

Frequency – The number of complete pressure fluctuations per second above and below ambient pressure, measured in cycles per second (Hertz [Hz]). Normal human hearing is between 20 and 20,000 Hz. Infrasonic sounds are below 20 Hz and ultrasonic sounds are above 20,000 Hz.

Frequency spectrum – The distribution of frequencies that comprise a sound.

Hertz (Hz) – The units of frequency where 1 Hz equals 1 cycle per second.

JEB – Joint Expeditionary Base.

Kilohertz (kHz) – 1,000 Hz.

L_{eq} – *Equivalent Average Sound Pressure Level (or Energy-Averaged Sound Level).* The decibel level of a constant noise source that would have the same total acoustical energy over the same time interval as the actual time-varying noise condition being measured or estimated. Leq values must be associated with an explicit or implicit averaging time in order to have practical meaning. The use of A-weighted, C-weighted, or Z-weighted (flat) decibel units sometimes is indicated by LA_{eq}, LC_{eq}, or LZ_{eq}, respectively.

LZ_{eq} – Z-weighted, L_{eq}, sound pressure level.

LZF – Z-weighted Fast RMS sound pressure level.

LZF_{max} – Maximum Z-weighted Fast RMS sound pressure level.

LZI_{max} – Maximum Z-weighted Impulse RMS sound pressure level.

LZ_{max} – Maximum sound pressure level during a measurement period or a noise event.

LZ_{peak} – Z-weighted peak sound pressure level.

microPascal (μPa) – The Pascal (symbol Pa) is the SI unit of pressure. It is equivalent to one Newton per square meter. There are 1,000,000 microPascals in one Pascal.

Peak sound pressure level (L_{PEAK}) – The largest absolute value of the instantaneous sound pressure. This pressure is expressed in decibels (referenced to a pressure of 1 μPa for water and 20 μPa for air) or in units of pressure, such as μPa or pounds per square Inch.

Root mean square (RMS) sound pressure level – Decibel measure of the square root of mean square (RMS) pressure. For impulses, the average of the squared pressures over the time that comprise that portion of the waveform containing 90 percent of the sound energy of the impulse.

SLM – Sound level meter.

Sound – Small disturbances in a fluid from ambient conditions through which energy is transferred away from a source by progressive fluctuations of pressure (or sound waves).

Sound exposure – The integral over all time of the square of the sound pressure of a transient waveform.

Sound exposure level (SEL) – The time integral of frequency-weighted squared instantaneous sound pressures. Proportionally equivalent to the time integral of the pressure squared. Sound energy associated with a pile driving pulse, or series of pulses, is characterized by the SEL. SEL is the constant sound level in one second, which has the same amount of acoustic energy as the original time-varying sound (i.e., the total energy of an event). SEL is calculated by summing the cumulative pressure squared over the time of the event ($1\mu Pa^2$-sec**)**.

Sound pressure level (SPL) – An expression of the sound pressure using the decibel (dB) scale and the standard reference pressures of 1 μPa for water, and 20 μPa for air and other gases. Sound pressure is the sound force per unit area, usually expressed in microPascals (or microNewtons per square meter), where 1 Pascal is the pressure resulting from a force of 1 Newton exerted over an area of 1 square meter. The SPL is expressed in dB as 20 times the logarithm to the base 10 of the ratio between the pressure exerted by the sound to a reference sound pressure. SPL is the quantity directly measured by a sound level meter.

Z-weighted – Z-weighting is a flat frequency response of 10 Hz to 20 kHz ±1.5 dB. This response replaces the older "Linear" or "Unweighted" responses as these did not define the frequency range over which the meter would be linear.

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A

Time History of Pile Driving/Removal

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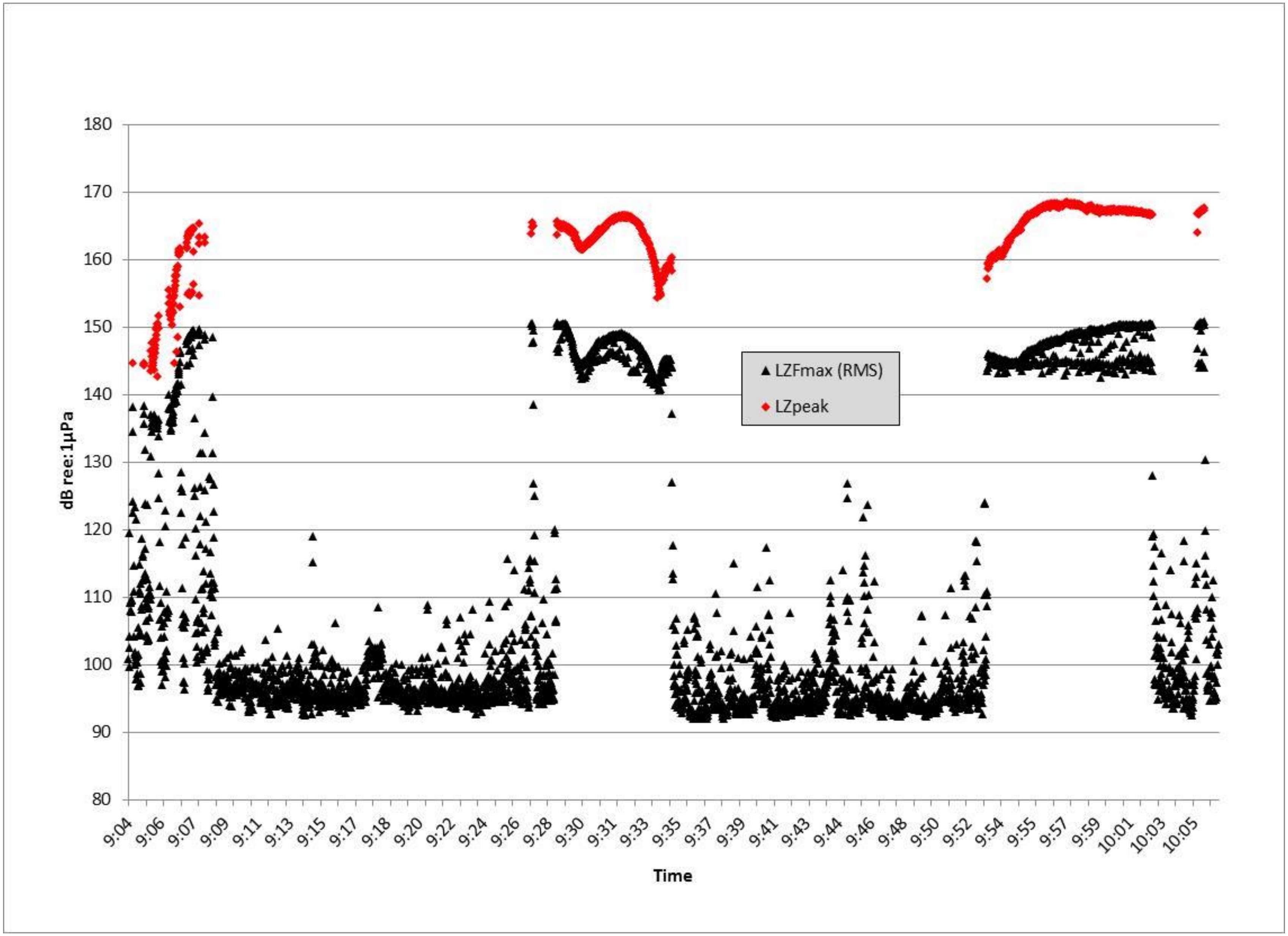

Figure A-1. Underwater Noise Measured at 36 Feet (11 Meters), Vibratory Driving Sheet Piles, JEB Little Creek, 28 May 2013.

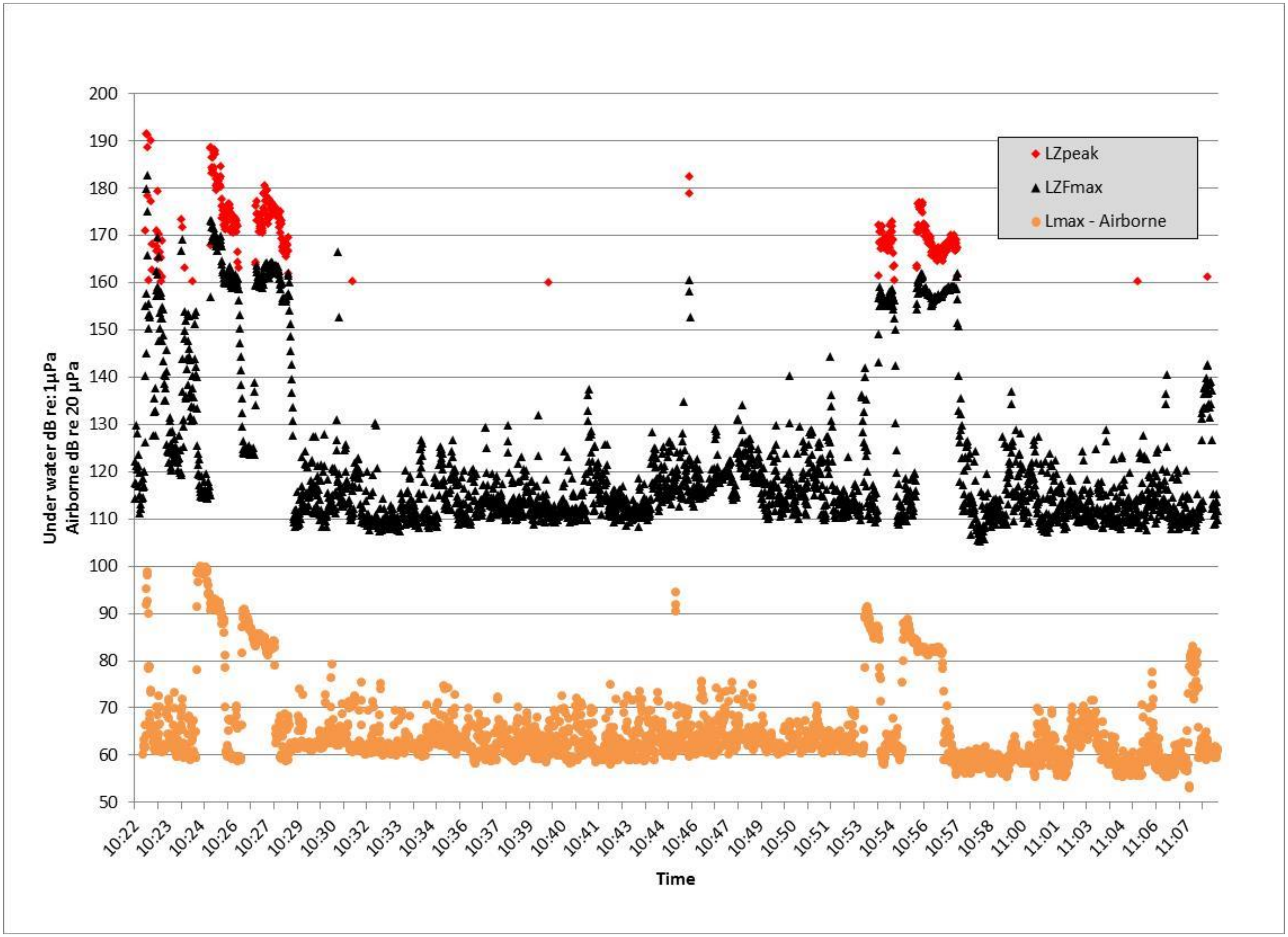

Figure A-2. Underwater Noise Measured at 30 Feet (9 Meters) Driving Sheet Piles, JEB Little Creek, 28 May 2013.

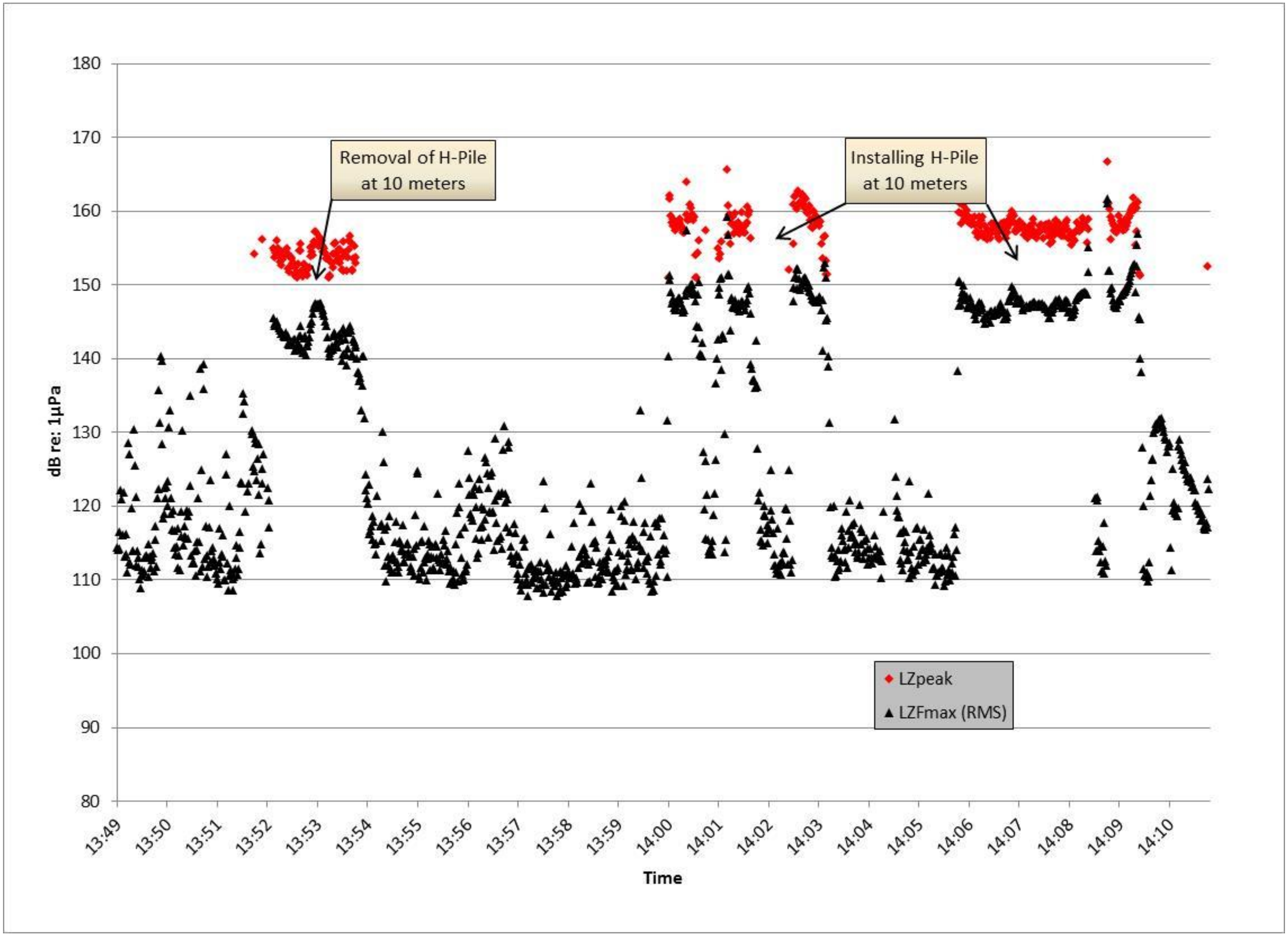

Figure A-3. Underwater Noise Measured at 33 Feet (10 Meters) Driving H-Piles, JEB Little Creek, 28 May 2013.

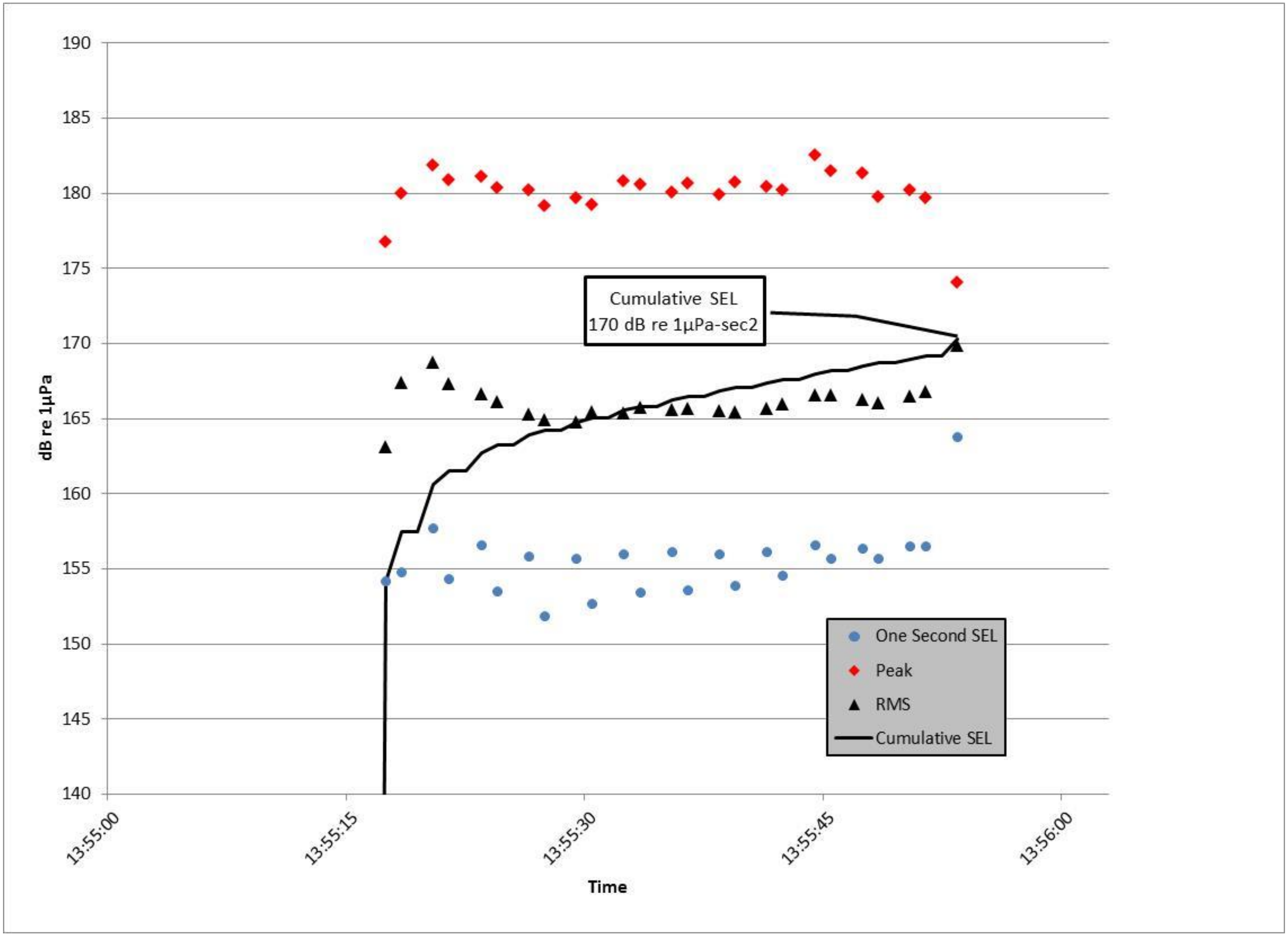

Figure A-3. Underwater Noise Recorded at 33 Feet (10 Meters), Proofing 24-inch Concrete Pile #1s, Craney Island, 29 May 2013.

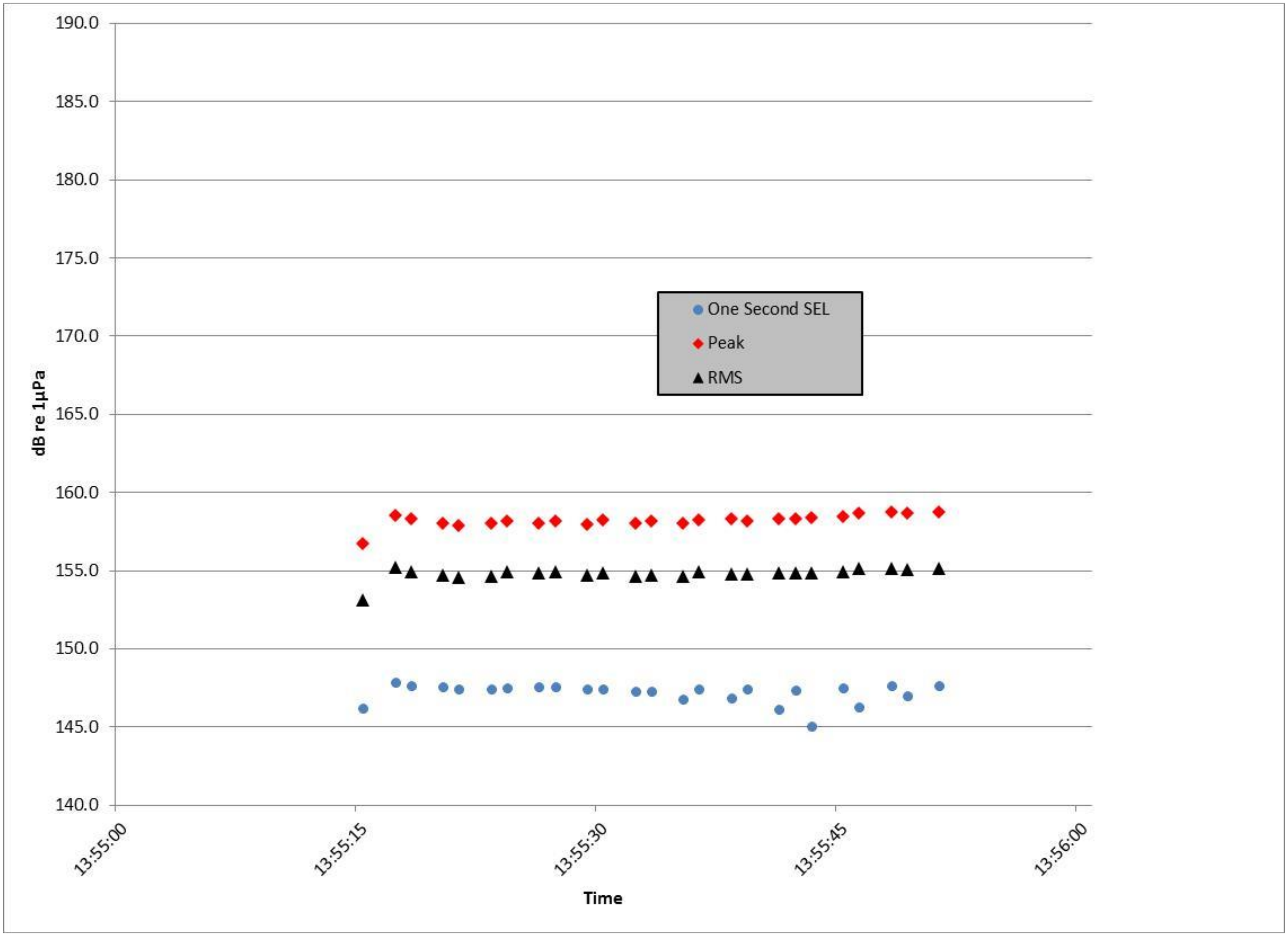

Figure A-4. Underwater Noise Recorded at 164 Feet (50 Meters) Proofing 24-inch Concrete Pile #1 at Craney Island, 29 May 2013.

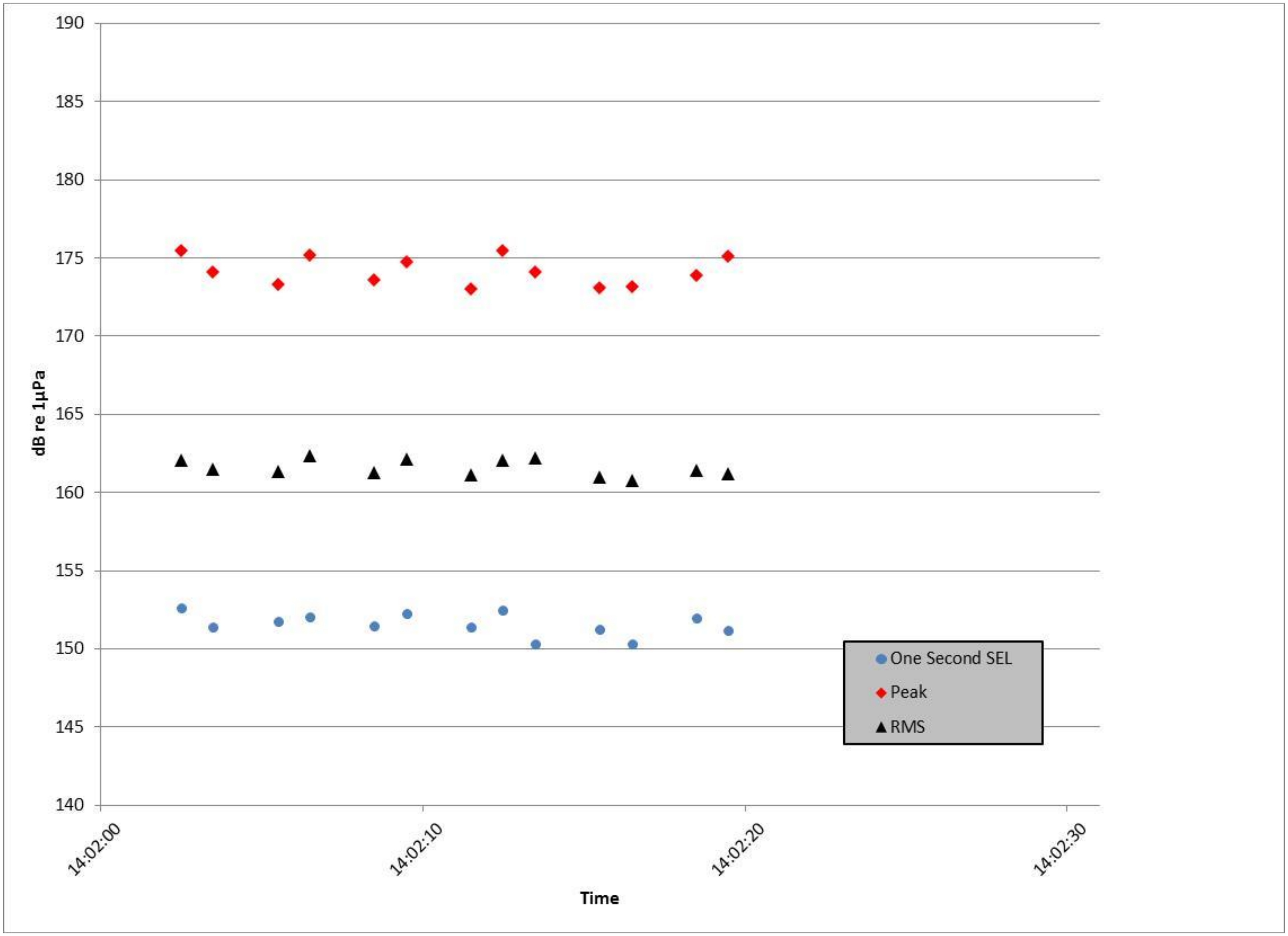

Figure A-5. Underwater Noise Recorded at 33 Feet (10 Meters) Proofing 24-inch Concrete Pile #2 at Craney Island, 29 May 2013.

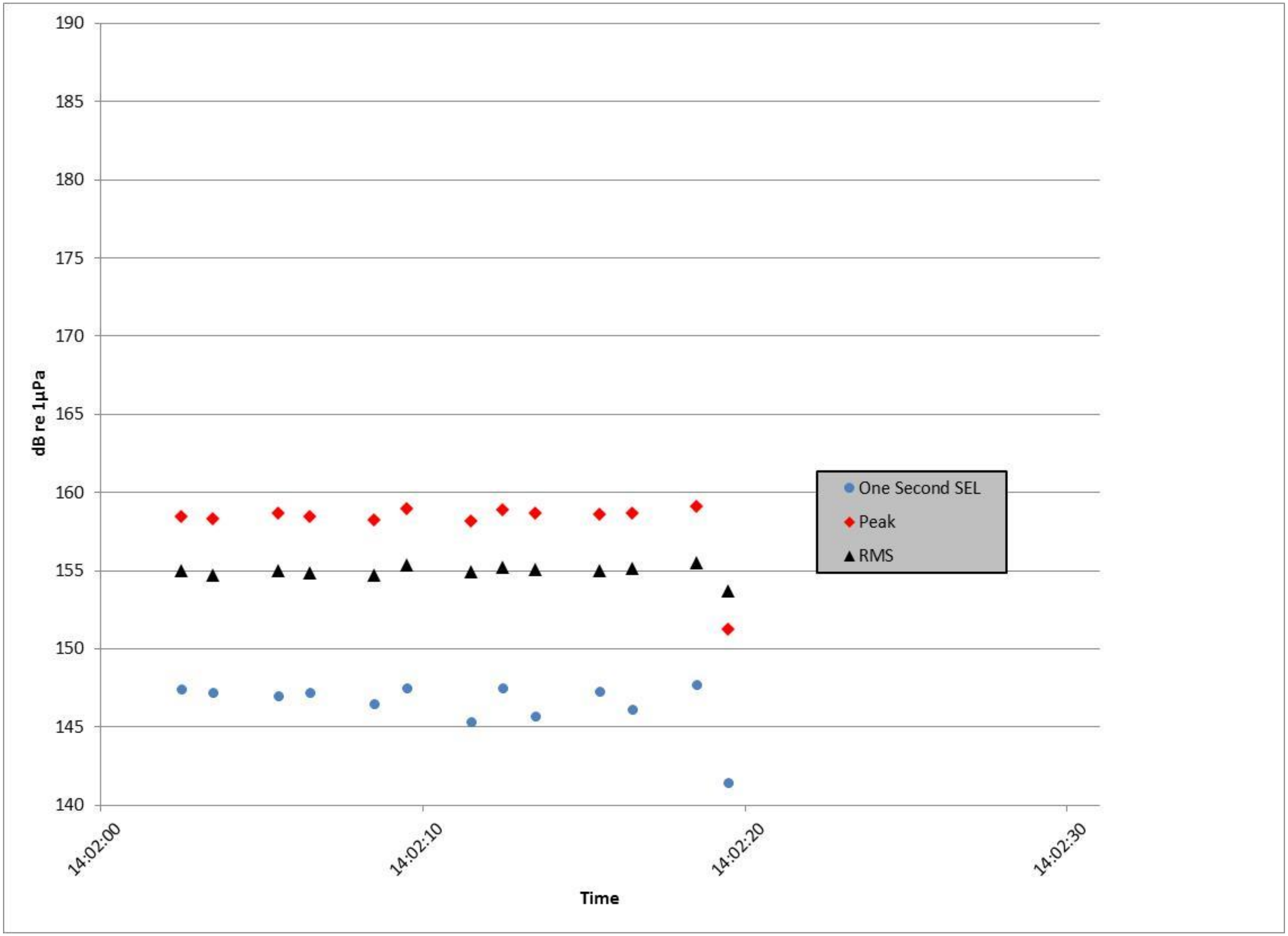

Figure A-6. Underwater Noise Recorded at 164 Feet (50 Meters) Proofing 24-inch Concrete Pile #2 at Craney Island, 29 May 2013.

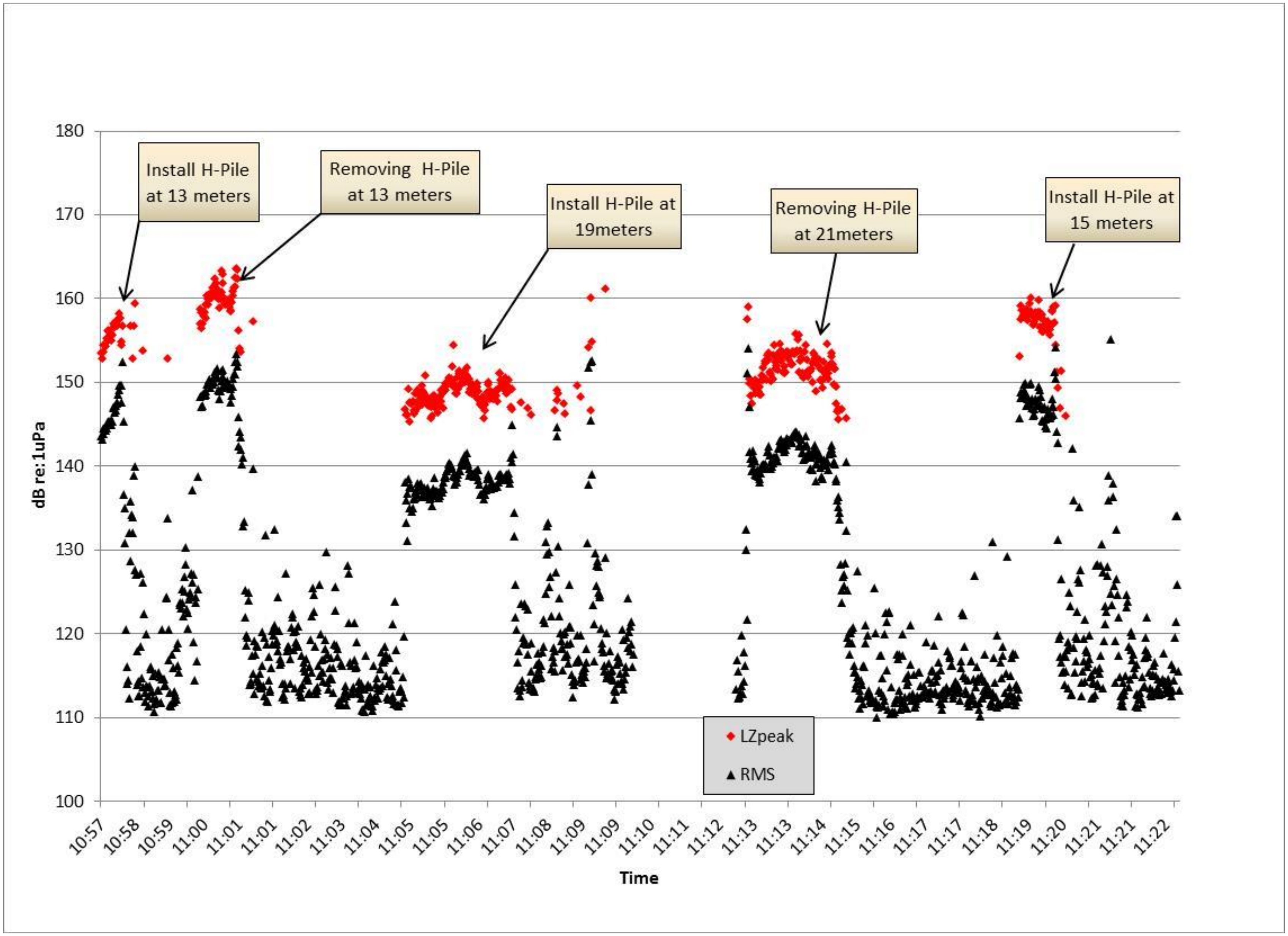

Figure A-7. Underwater Noise Recorded at 43-69 Feet (13-21 Meters) Driving H-Piles at JEB Little Creek, 30 May 2013.

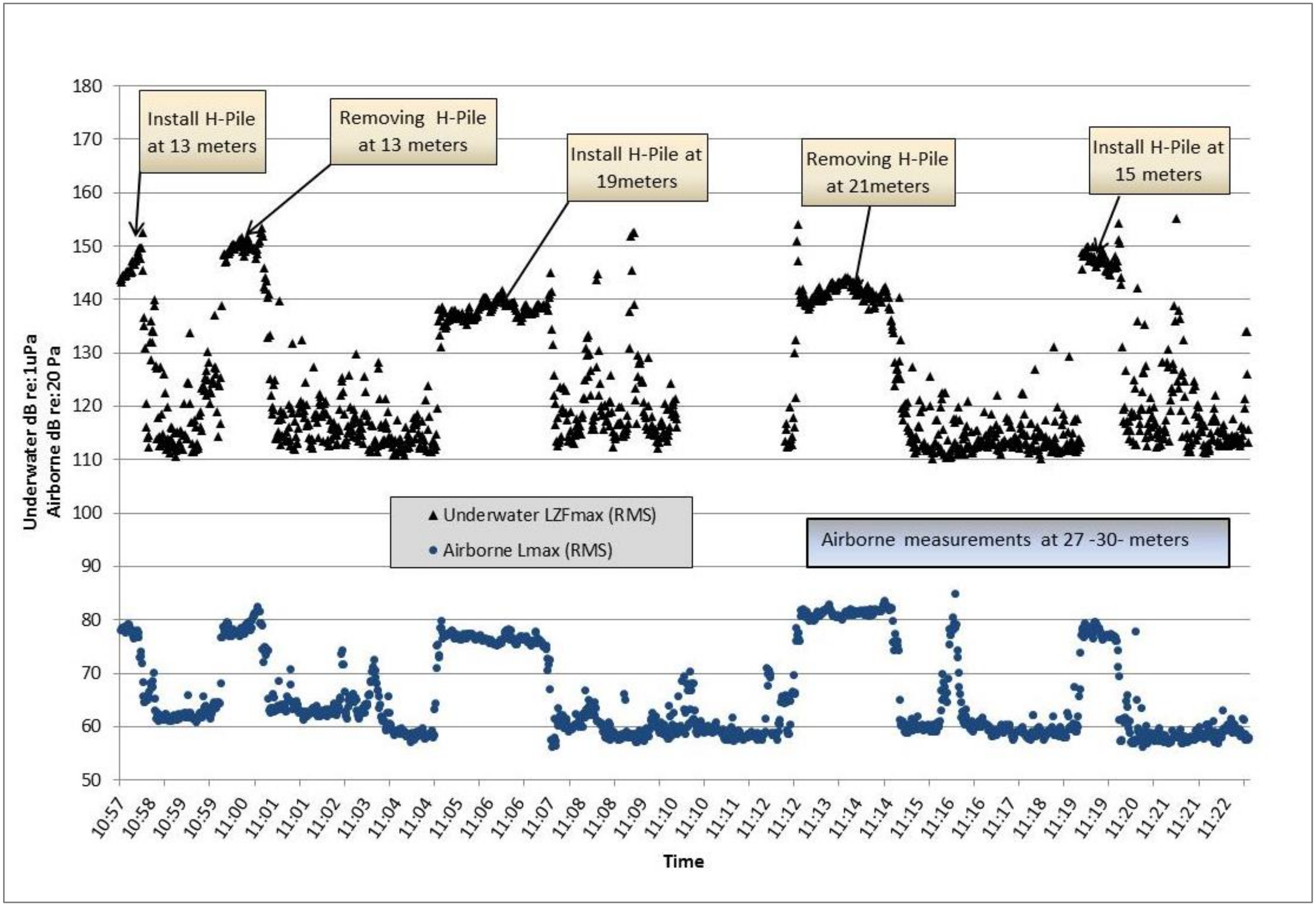

Figure A-8. Underwater Noise Recorded at 43-69 Feet (13-21 Meters) Driving H-Piles at JEB Little Creek, 30 May 2013.

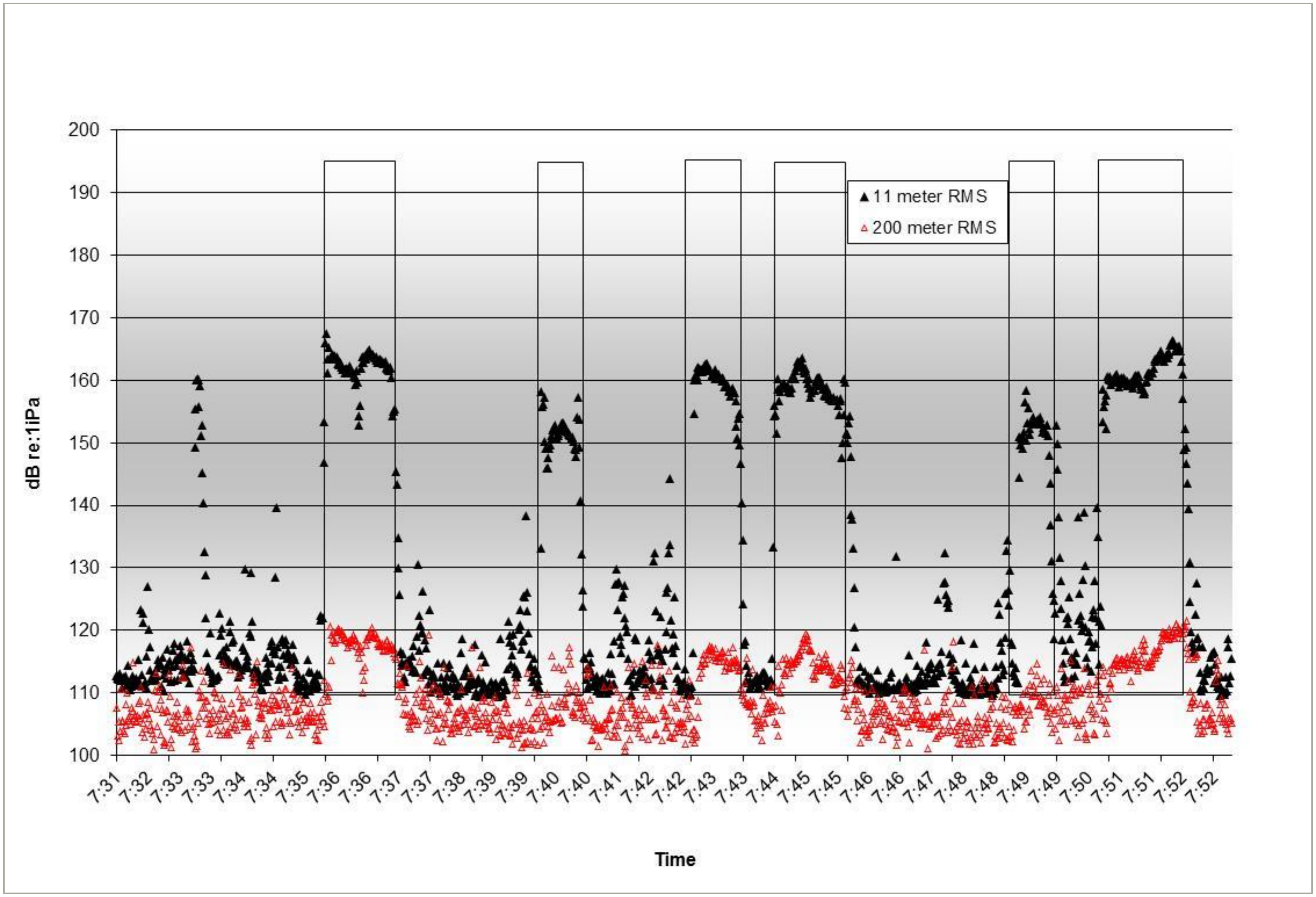

Figure A-9. Underwater Noise Recorded at 36 and 656 Feet (11-200 Meters) Driving Sheet Piles at JEB Little Creek, 30 May 2013.

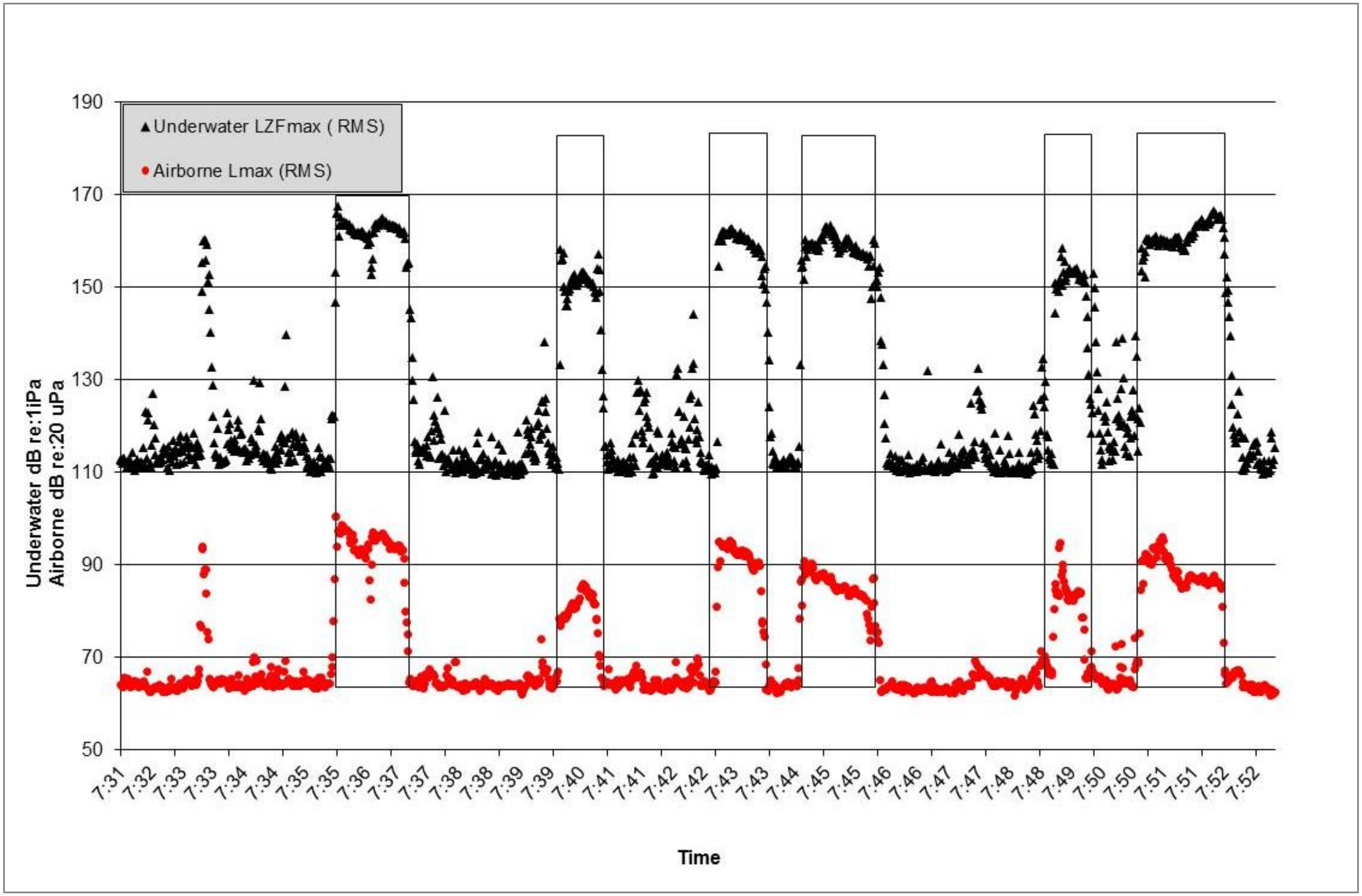

Figure A-10. Underwater Noise Recorded at 164 Feet (50 Meters) Proofing 24-inch Concrete Pile #2 at Craney Island, 29 May 2013.

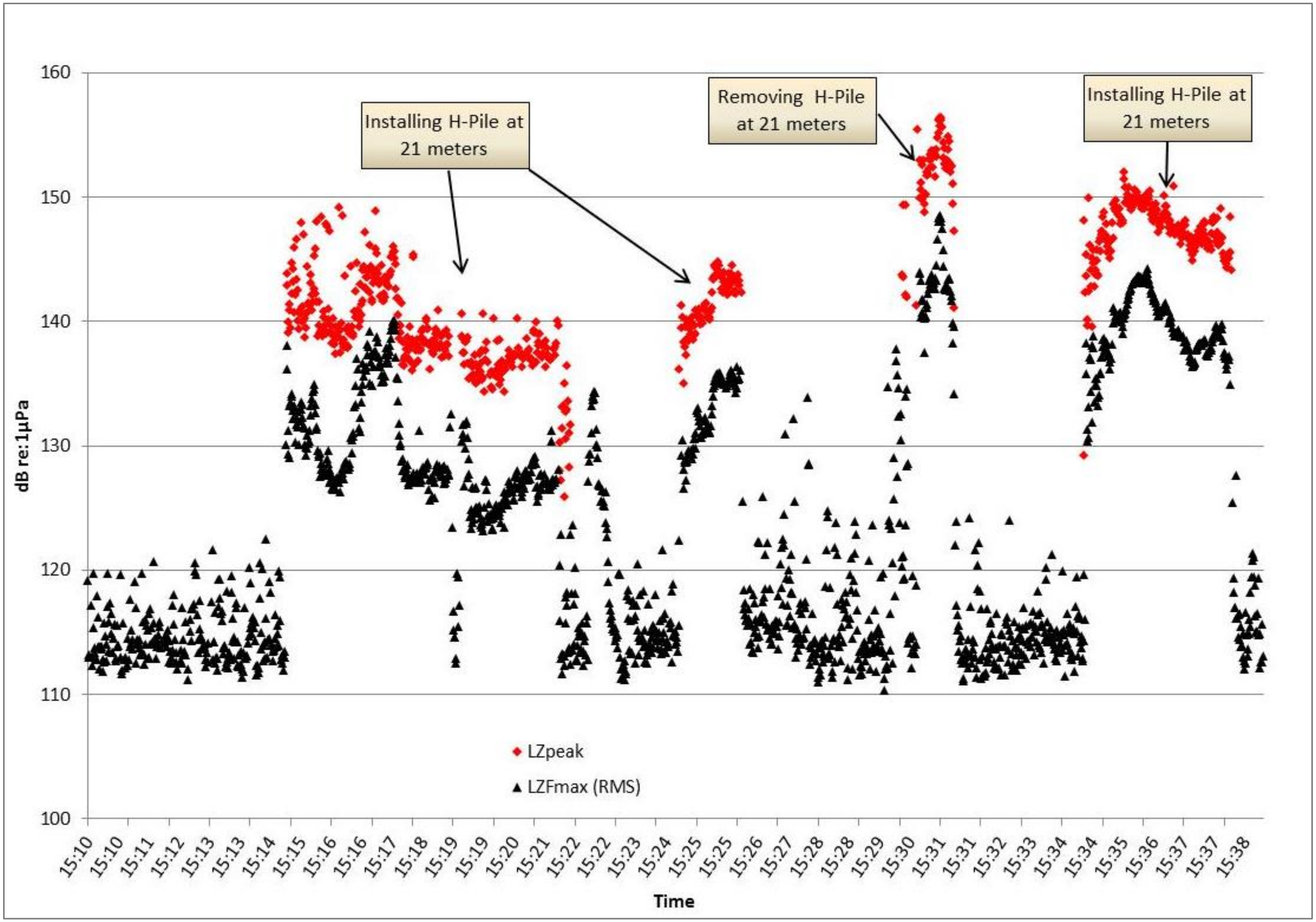

Figure A-11. Underwater Noise Recorded at 164 Feet (50 Meters) Proofing 24-inch Concrete Pile #2 at Craney Island, 29 May 2013.

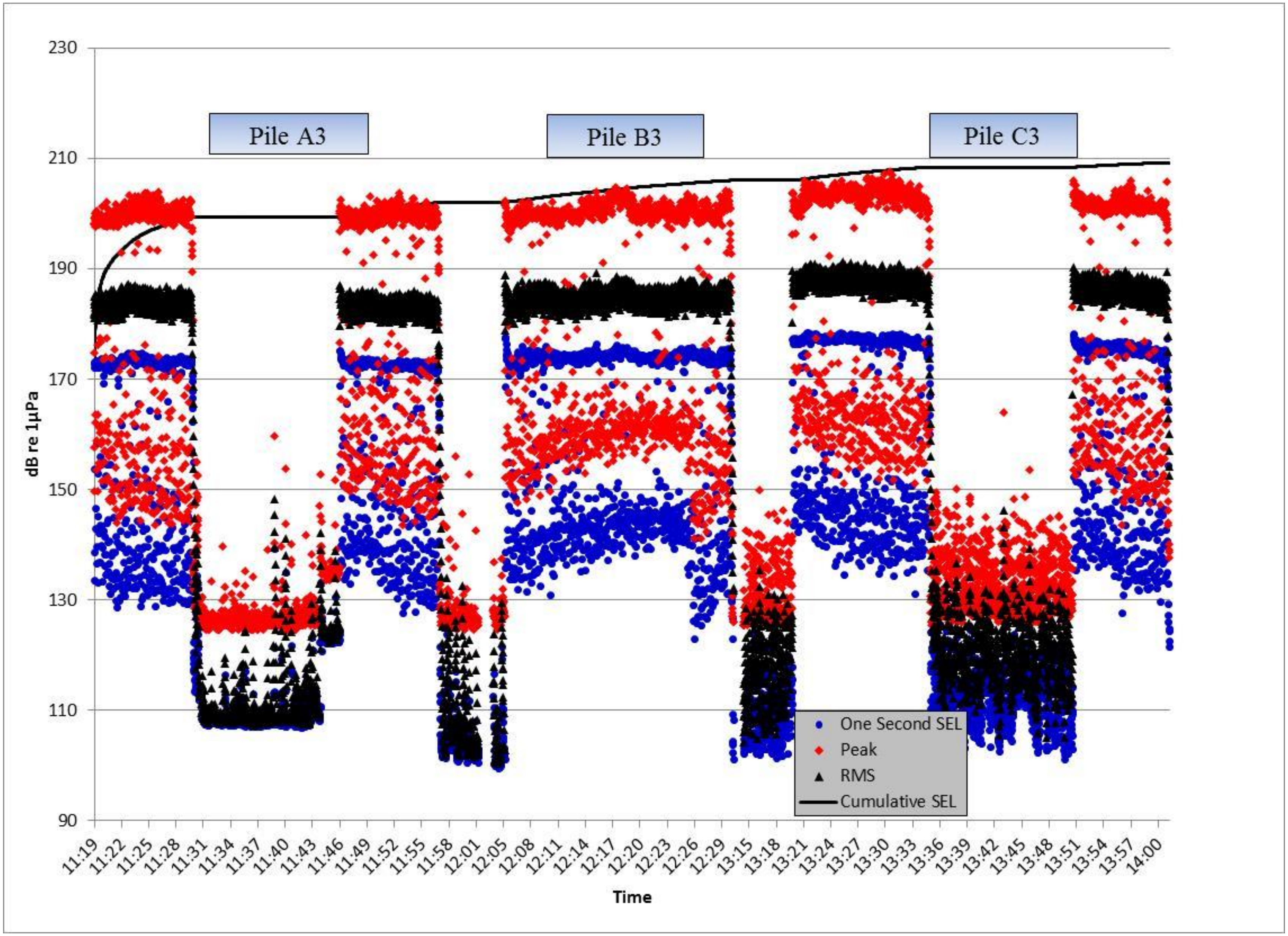

Figure A-12. Underwater Noise Measured at 33 Feet (10 Meters) Driving 48-inch Steel Shell Pile at Philadelphia Naval Shipyard 30 September 2014.

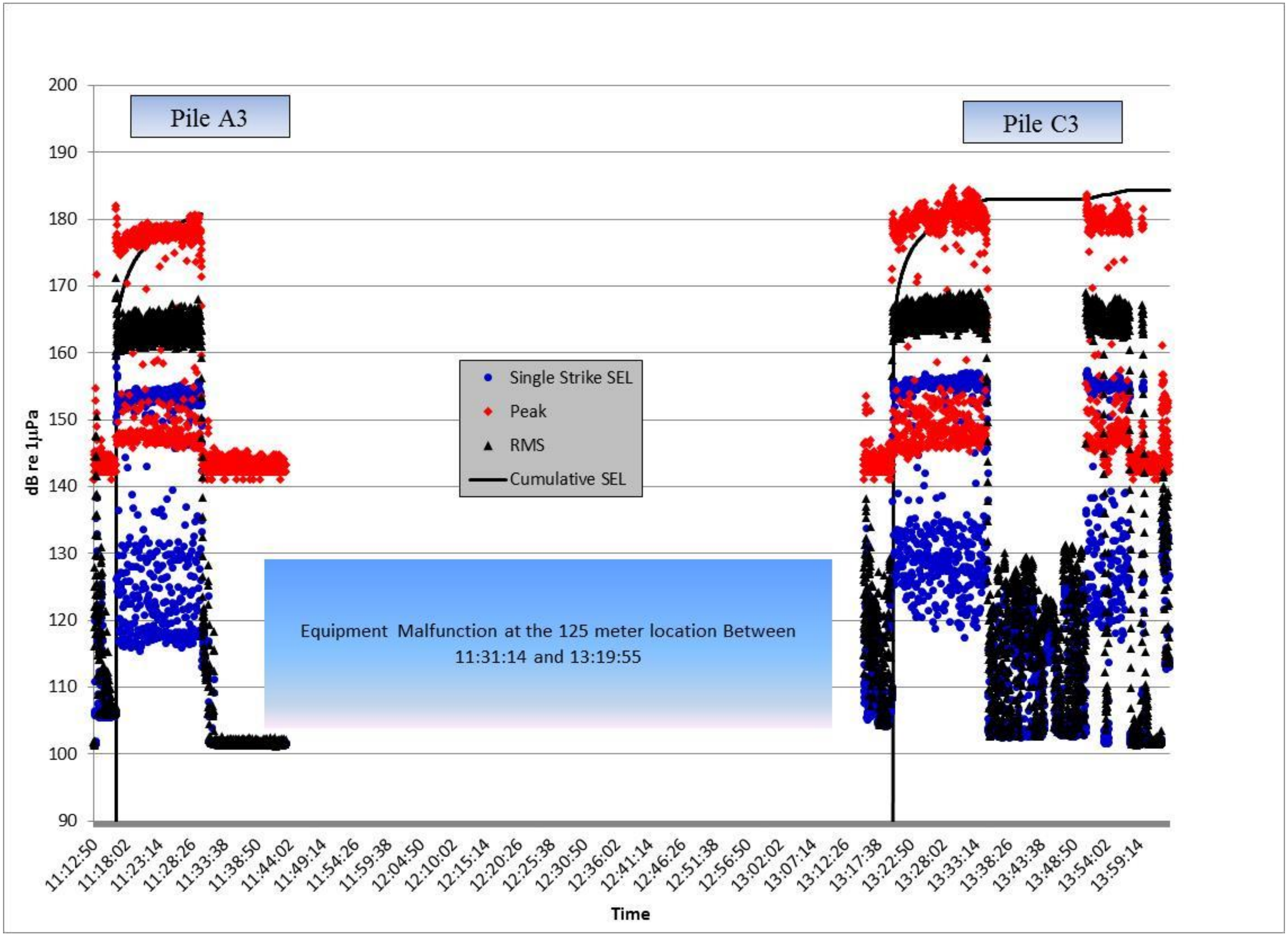

Figure A-13. Underwater Noise Recorded at 378 Feet (125 Meters) Driving 48-inch Steel Shell Pile at Philadelphia Naval Shipyard 30 September 2014.

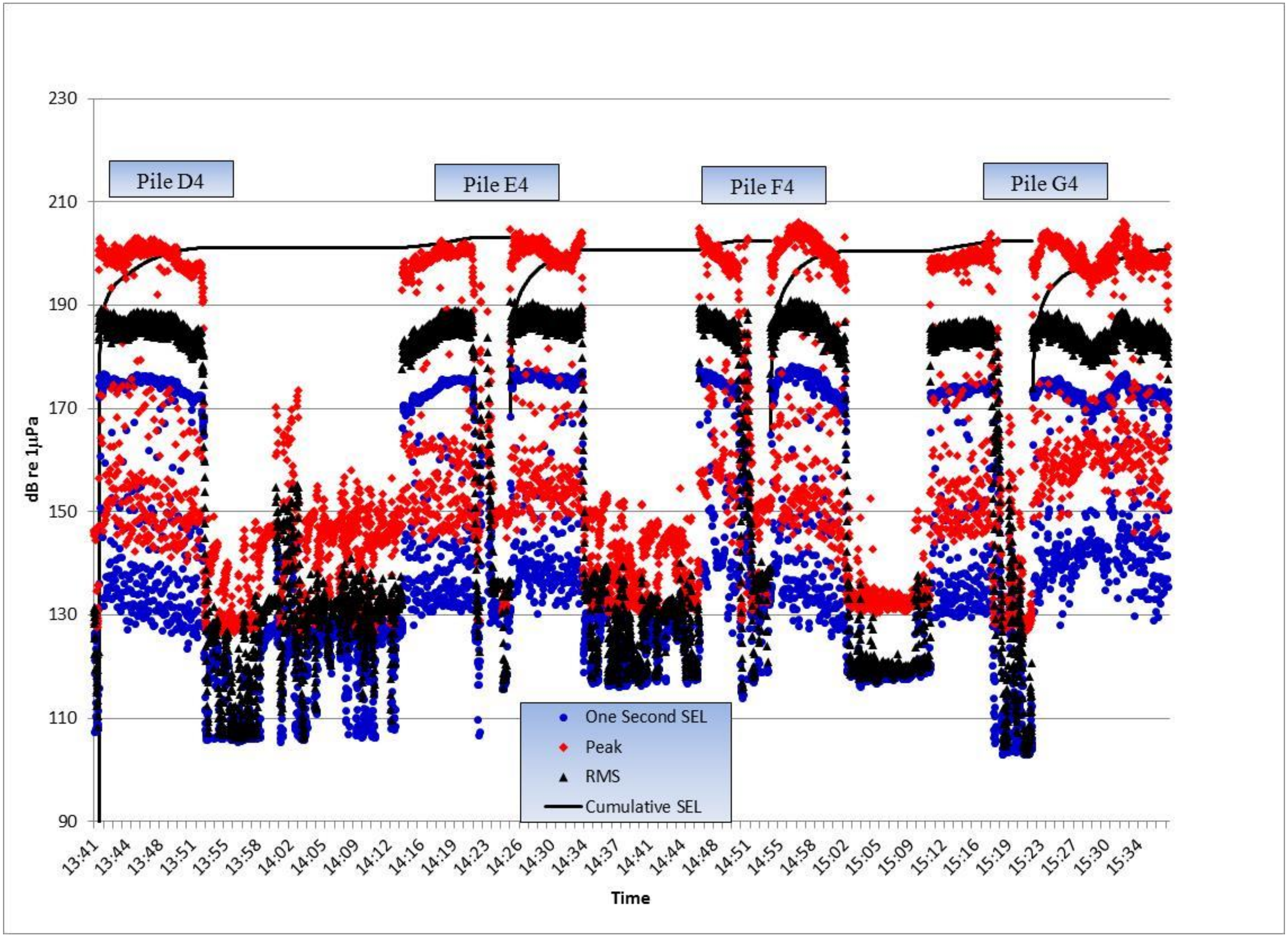

Figure A-14. Underwater Noise Recorded at 33 Feet (10 Meters) Driving 36-inch Steel Shell Pile at Philadelphia Naval Shipyard 01 October 2014.

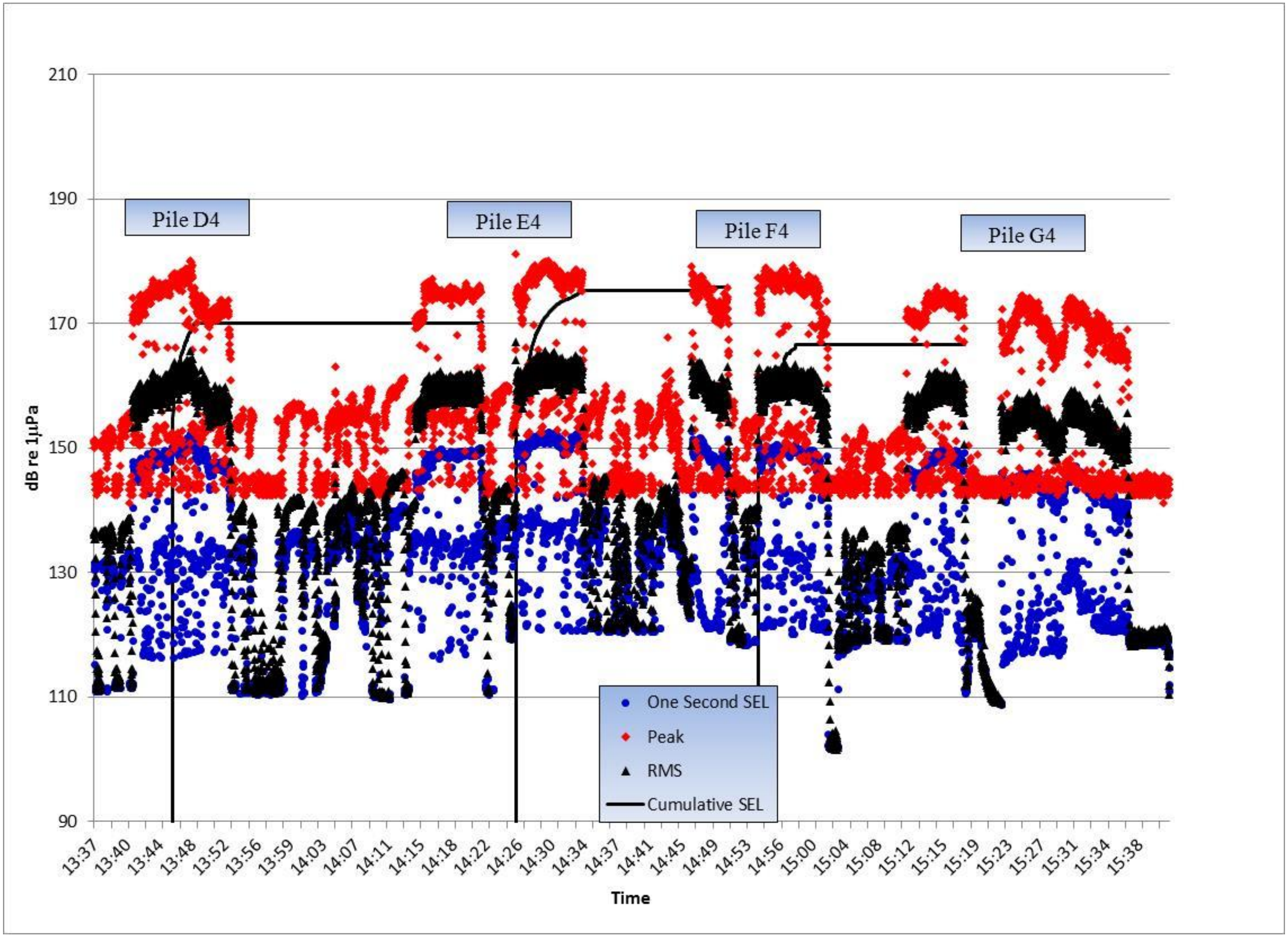

Figure A-15. Underwater Noise Recorded at 378 Feet (125 Meters) Driving 36-inch Steel Shell Pile at Philadelphia Naval Shipyard 01 October 2014.

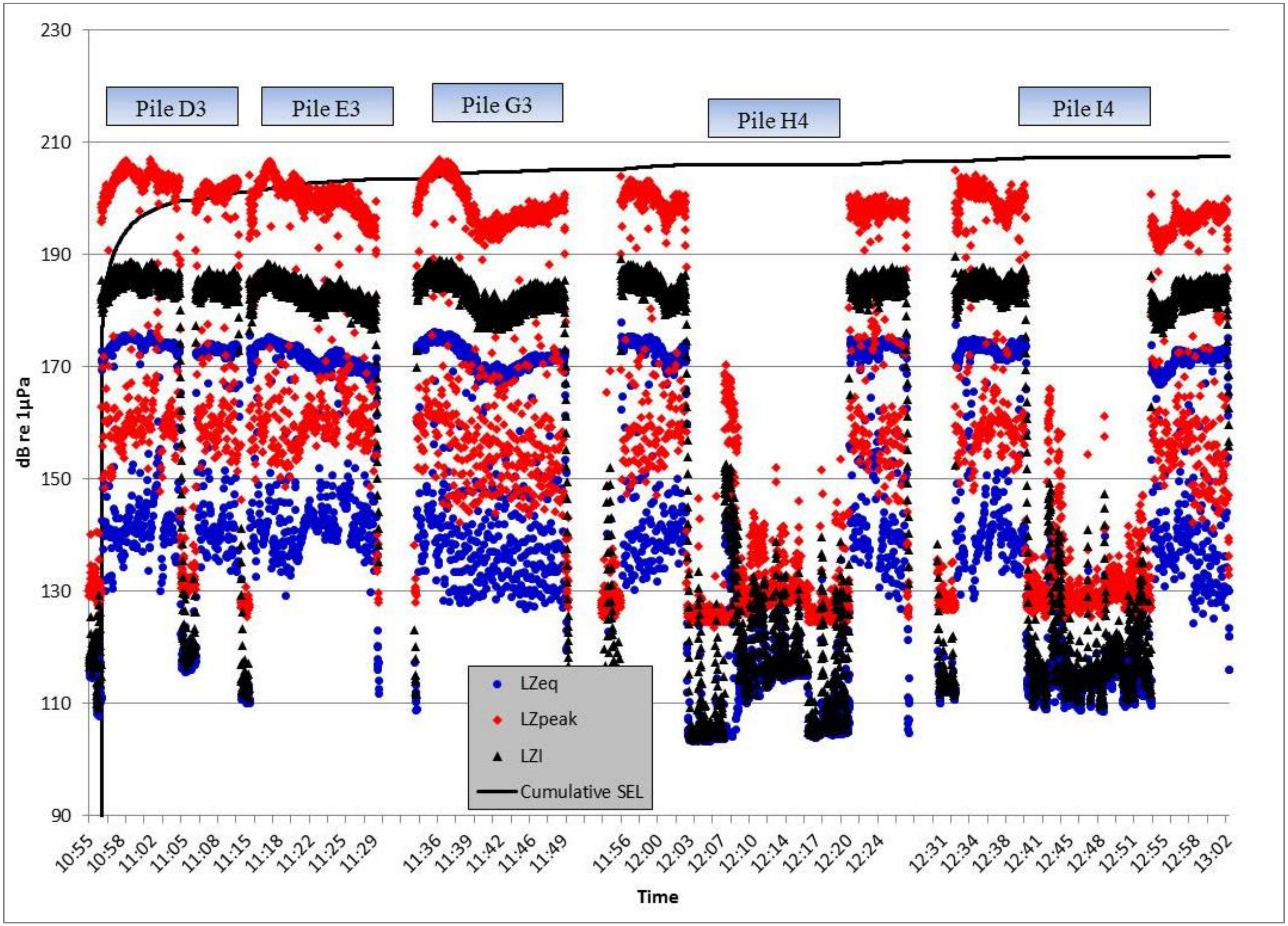

Figure A-16. Underwater Noise Recorded at 33 Feet (10 Meters) Driving 36-inch Steel Shell Pile at Philadelphia Naval Shipyard 02 October 2014.

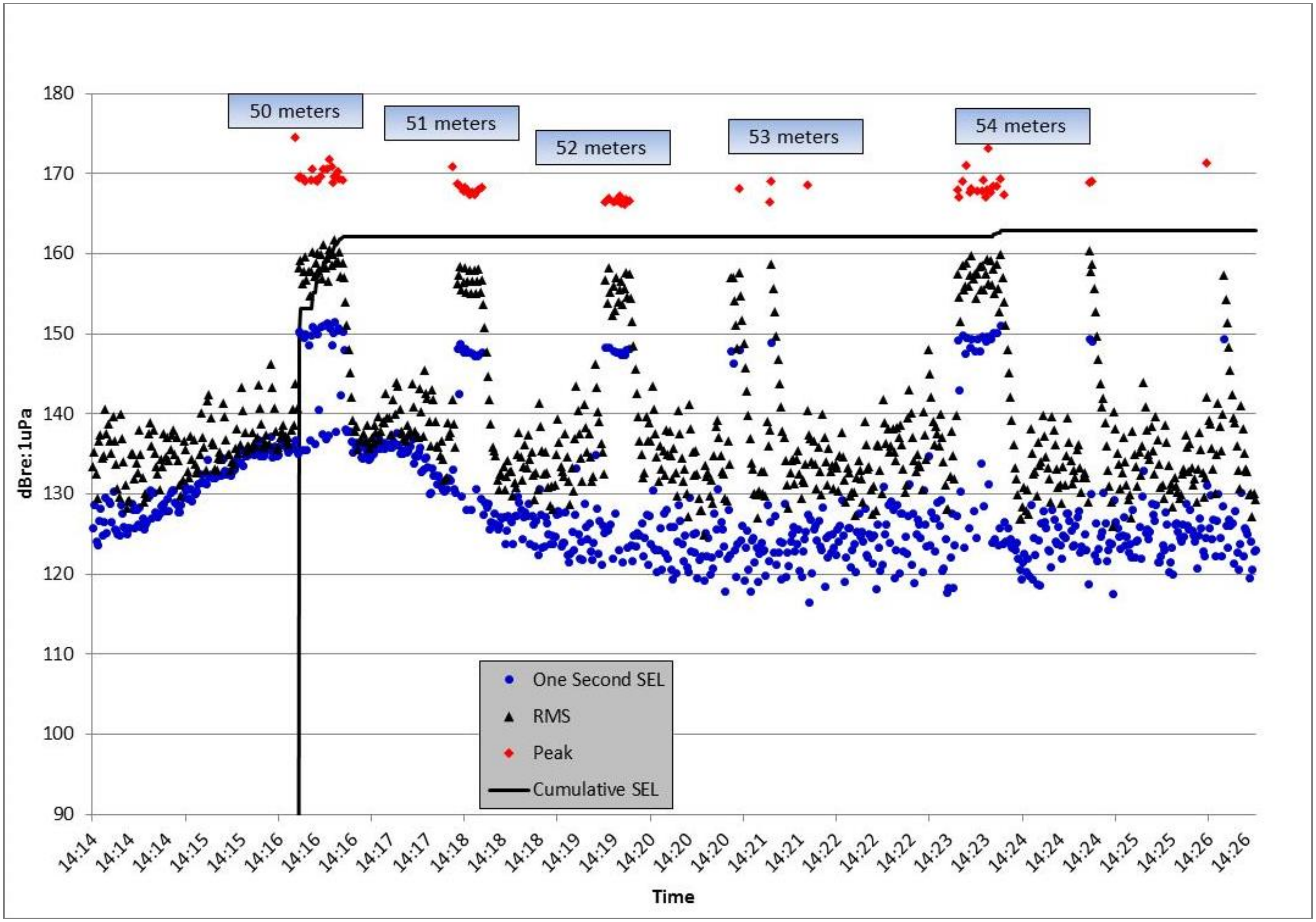

Figure A-17. Underwater Noise Recorded at 164 Feet (50 Meters to 177 feet (54 meters) Driving 24-inch Concrete Fender Piles at Naval Station Norfolk, 21 October 2014.

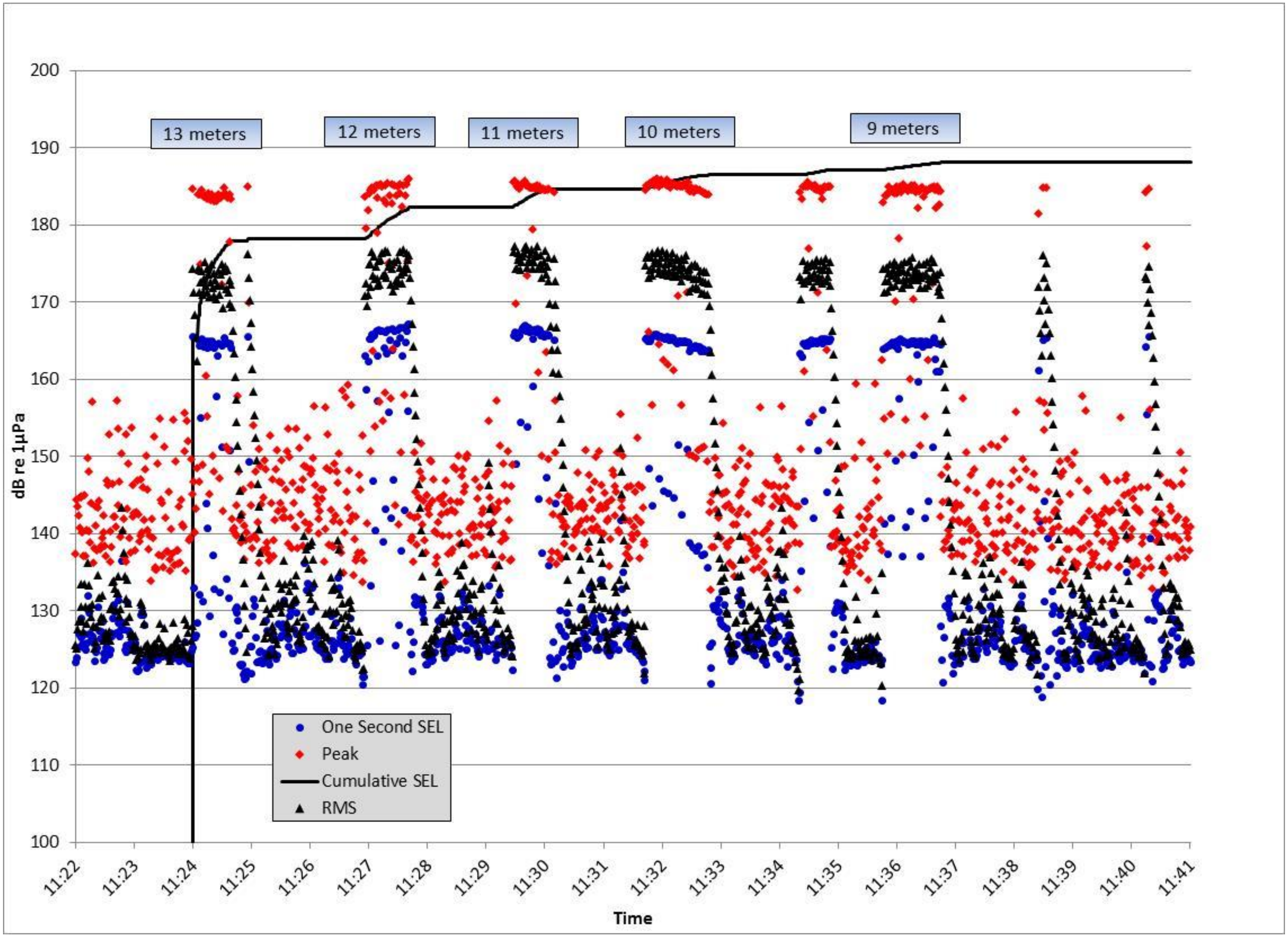

Figure A-18. Underwater Noise Recorded between 29 Feet (9 Meters) and 43 feet (13 meters) Driving 24-inch Concrete Fender Piles at Naval Station Norfolk, 25 October 2014..

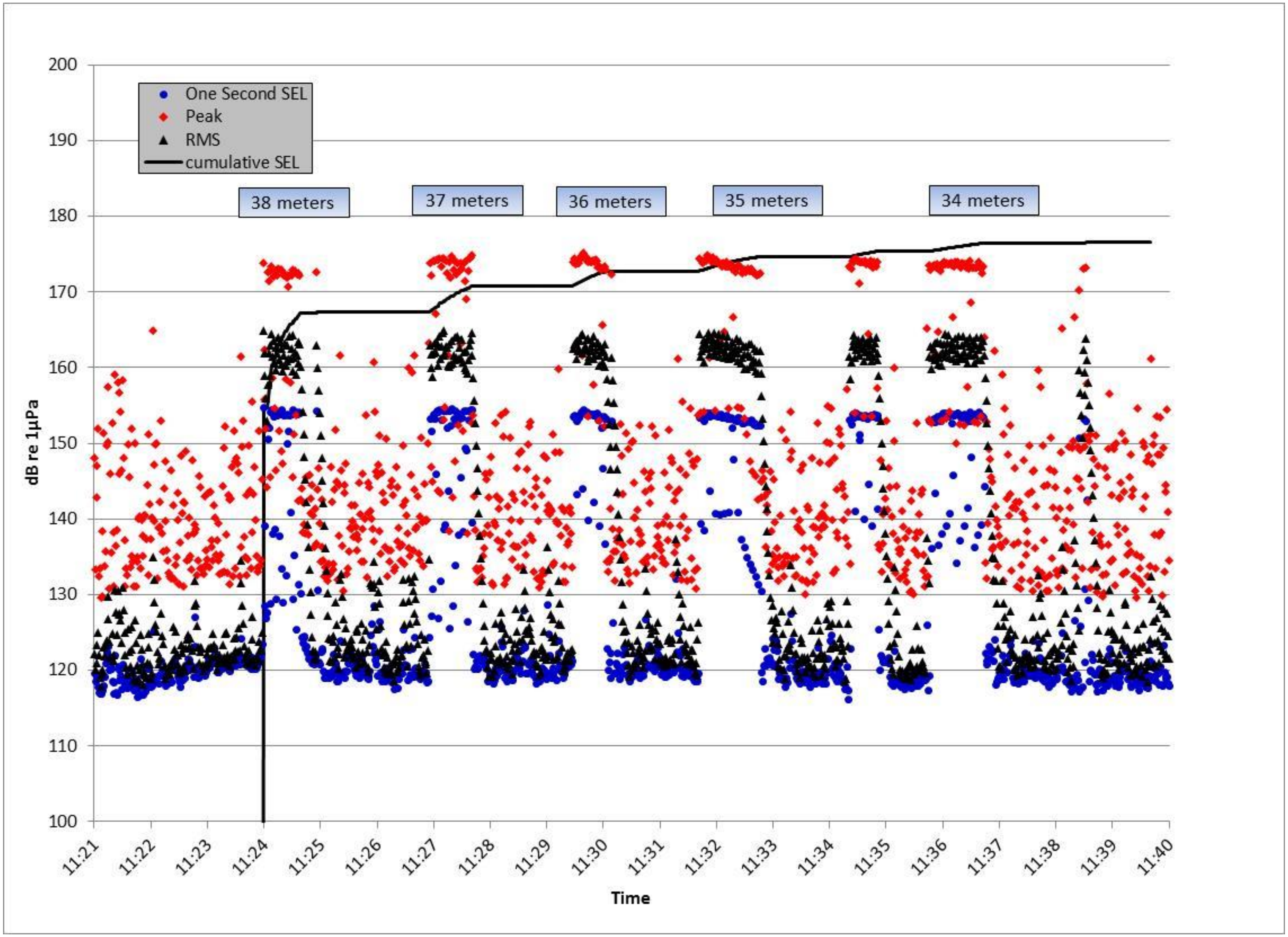

Figure A-19. Underwater Noise Measured Between 112 Feet (34 Meters) and 125 feet (38 meters) Driving 24-inch Concrete Fender Piles at Naval Station Norfolk 25 October 2014

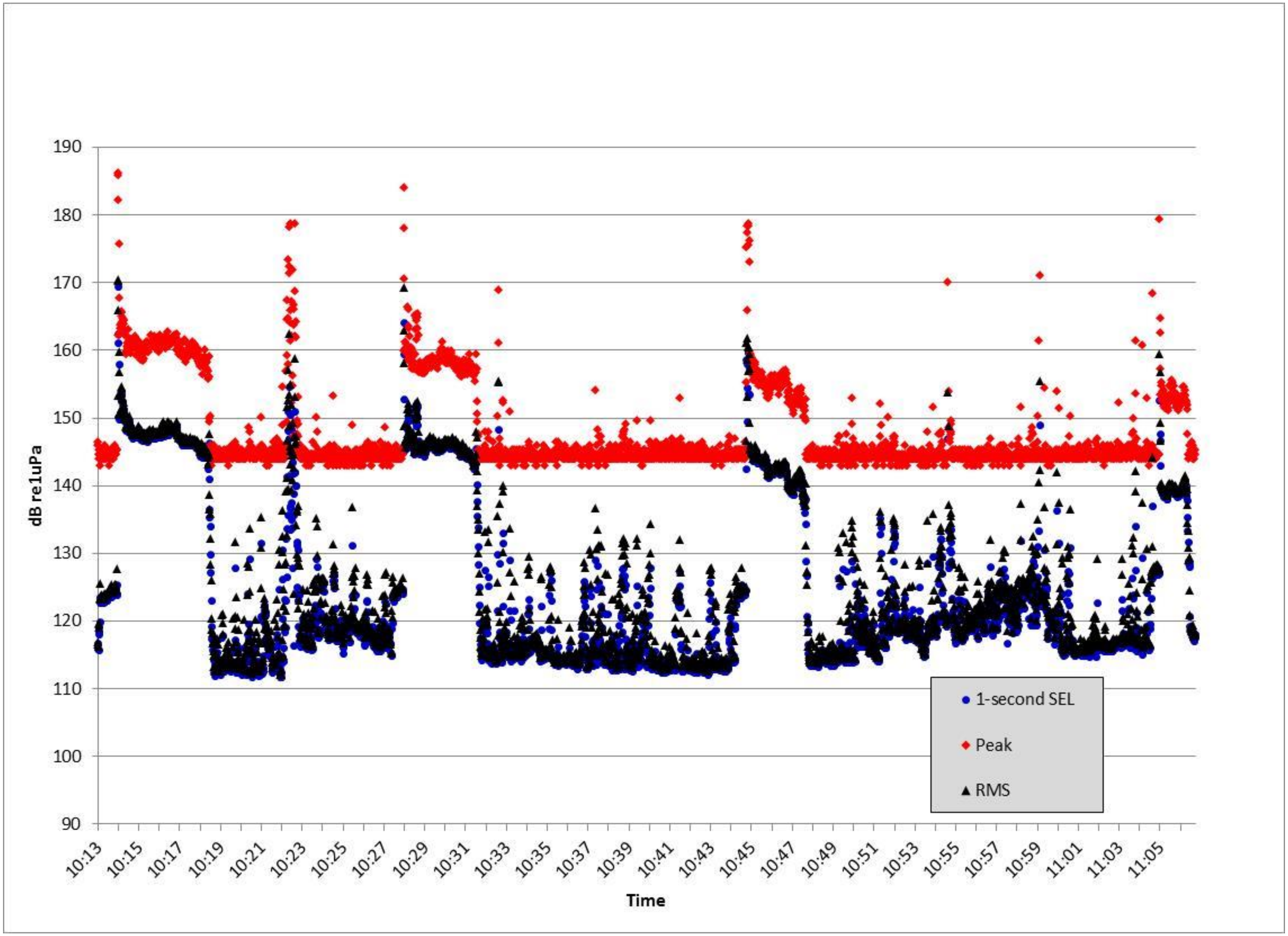

Figure A-20. Underwater Noise Recorded at 33 Feet (10 Meters) Removing 24-inch Steel Shell Piles with Vibratory Hammer 10 September 2015.

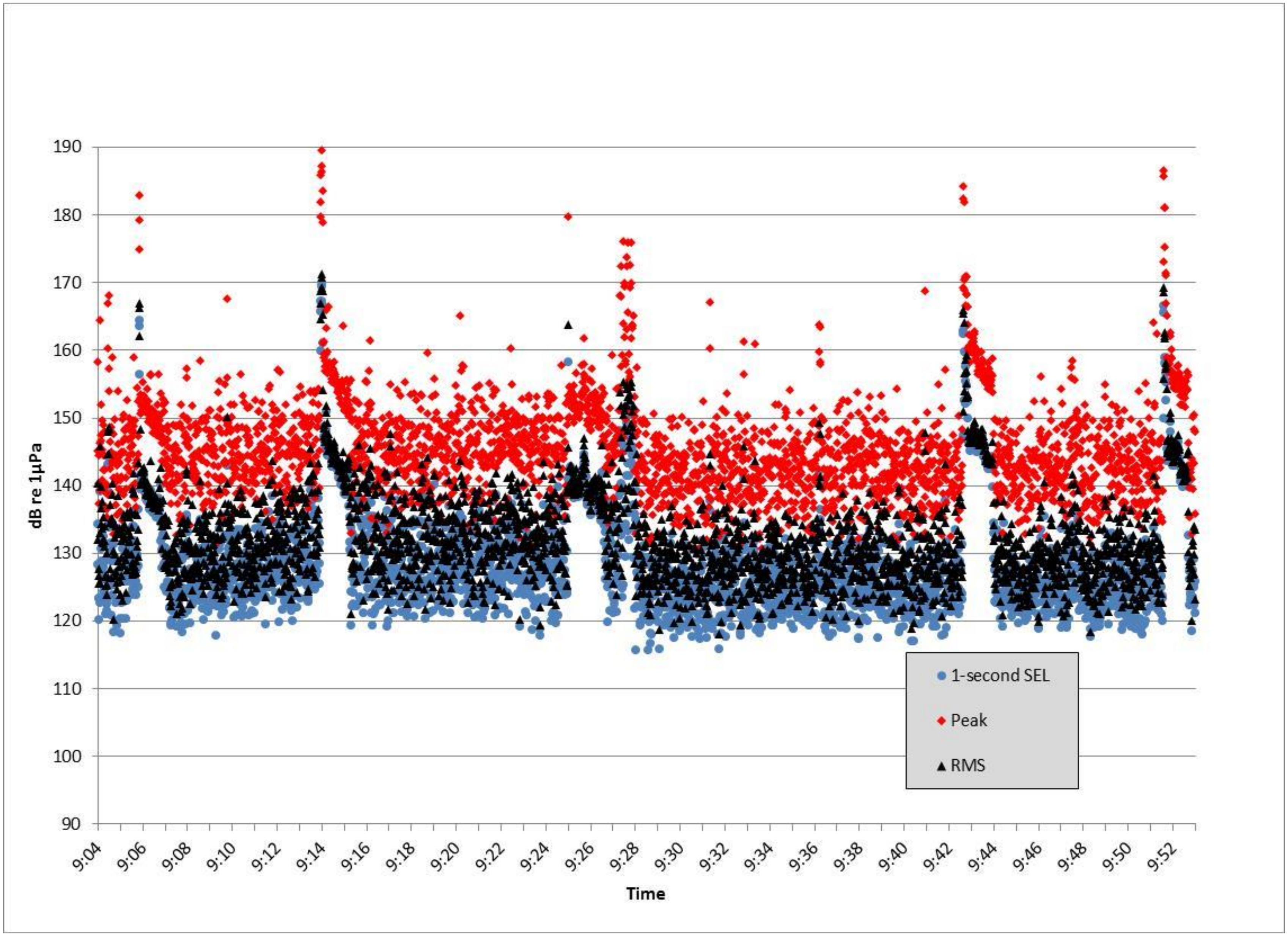

Figure A-21. Underwater Noise Measured at 33 Feet (10 Meters) Removing 24-inch Steel Shell Piles with Vibratory Hammer 11 September 2015 (Note the high background levels, this is due to the noise generated by the waves hitting the piles).

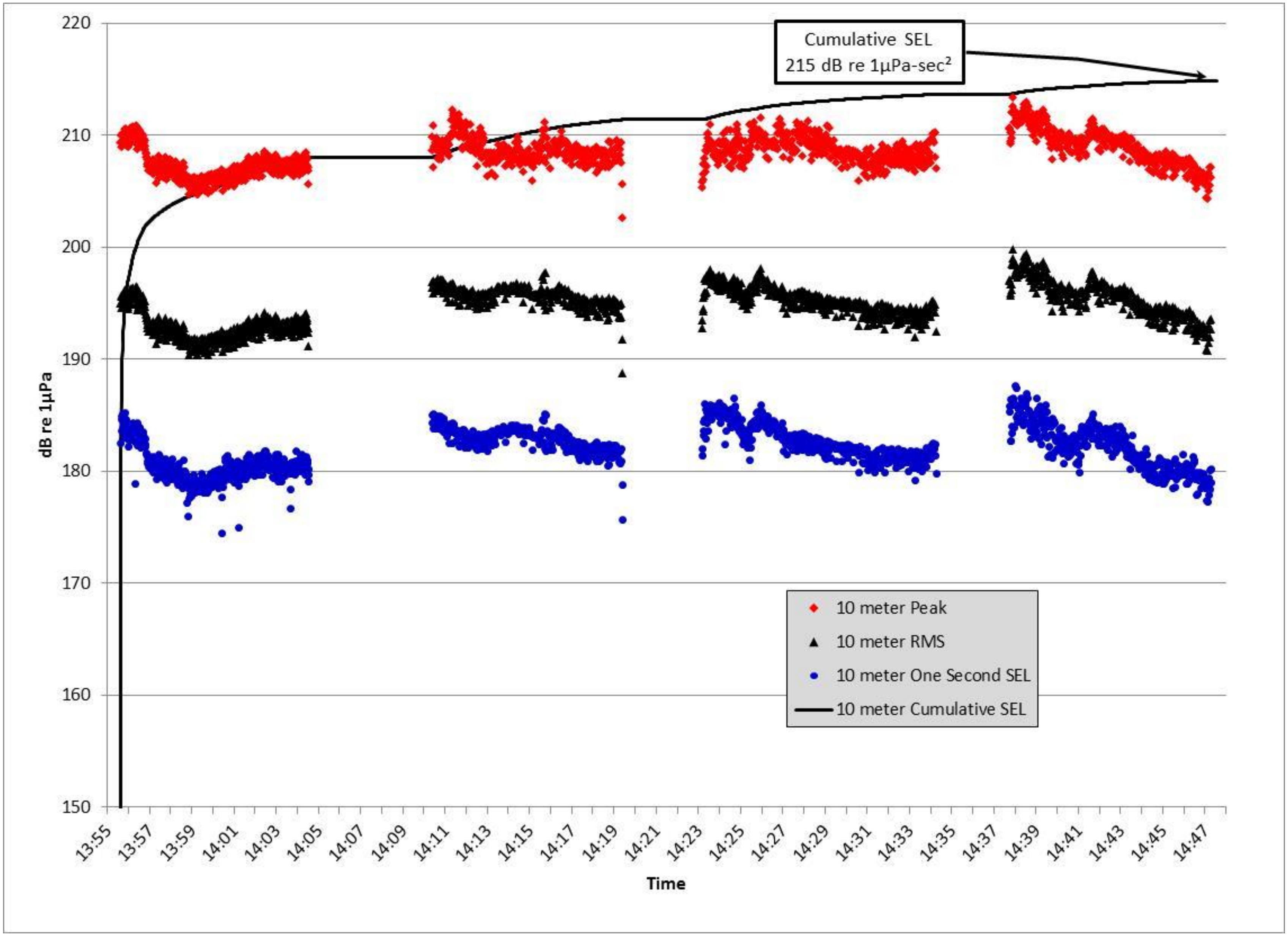

Figure A-22. Underwater Noise Recorded at 33 Feet (10 Meters) ELCAS Pile #1 at 10 meters at JEB Little Creek, 26 April 2016.

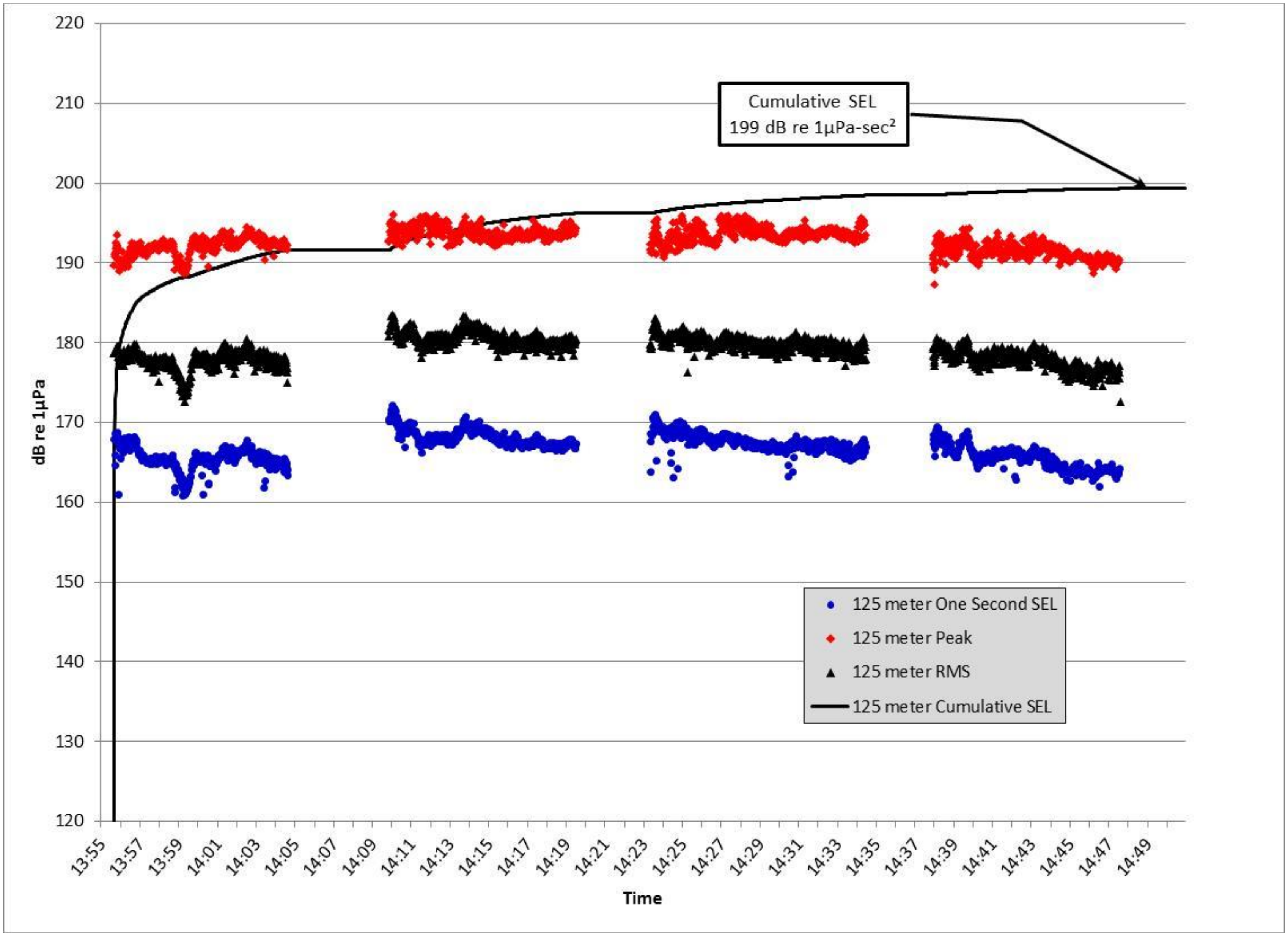

Figure A-23. Underwater Noise Recorded at 410 Feet (125 Meters) ELCAS Piles at JEB Little Creek, 26 April 2016.

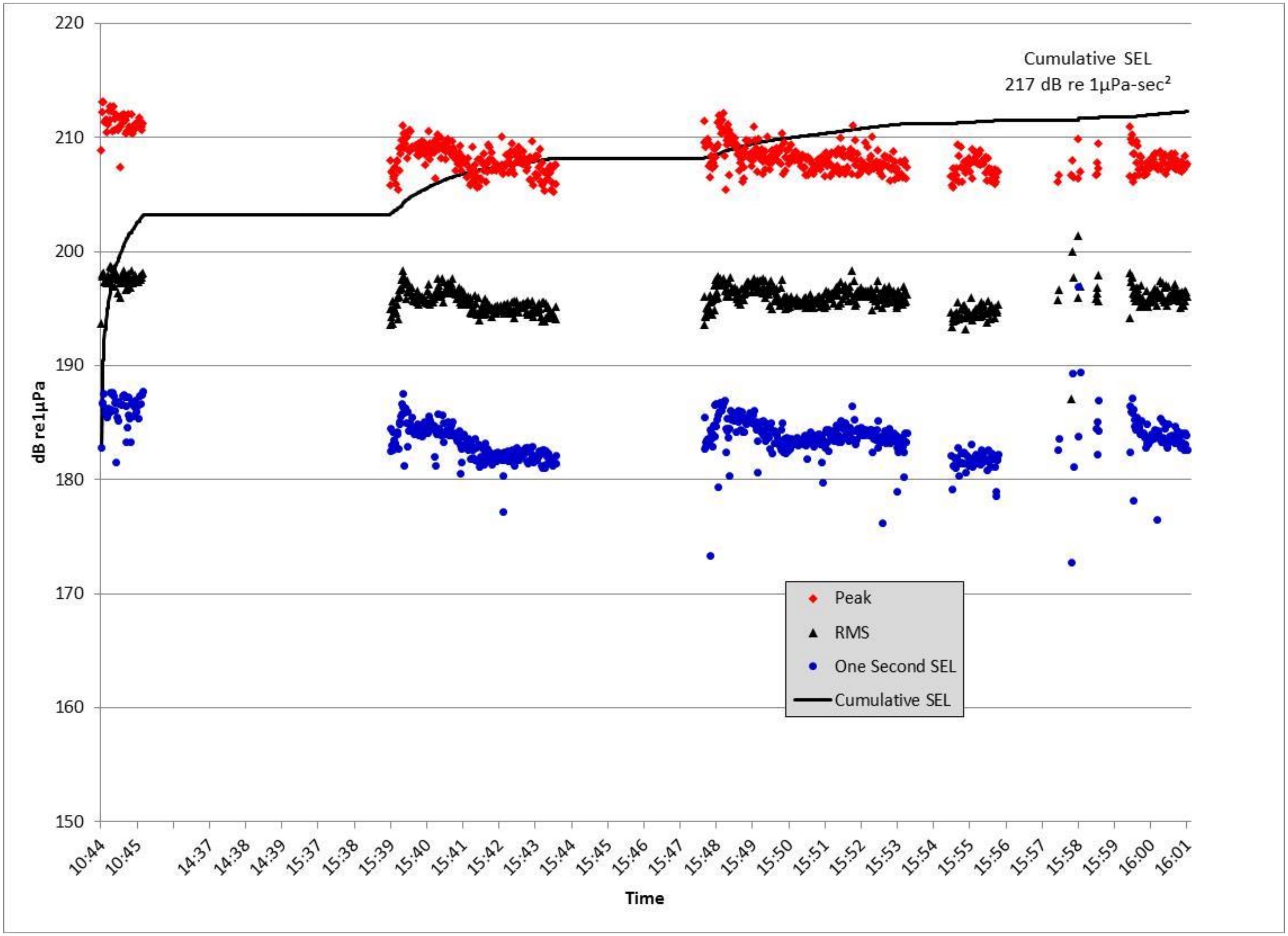

Figure A-24. Underwater Noise Recorded at 33 Feet (10 Meters) ELCAS Piles at JEB Little Creek, 27 April 2016.

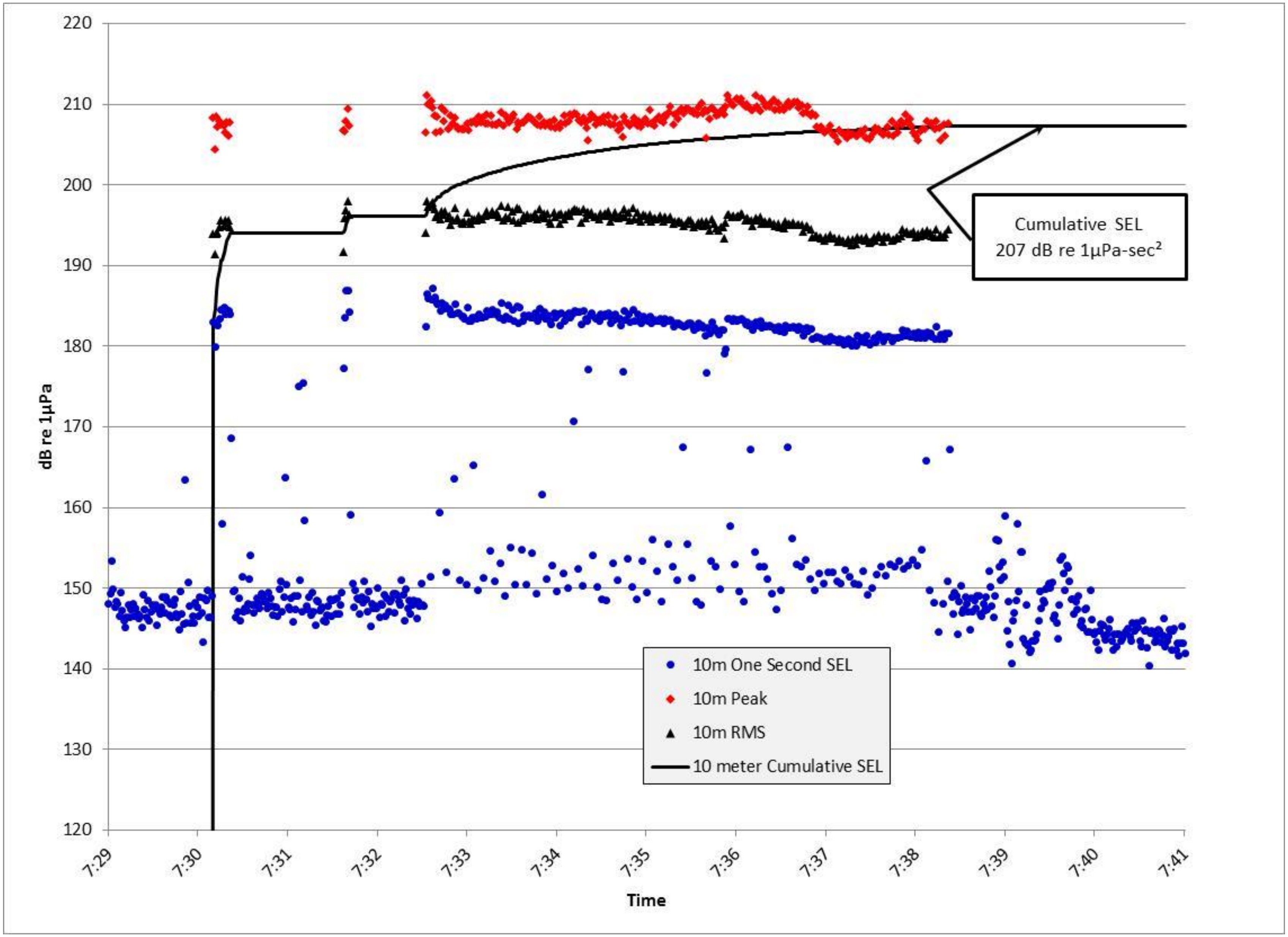

Figure A-25. Underwater Noise Recorded at 33 Feet (10 Meters) ELCAS Pile #1 at JEB Little Creek, 28 April 2016.

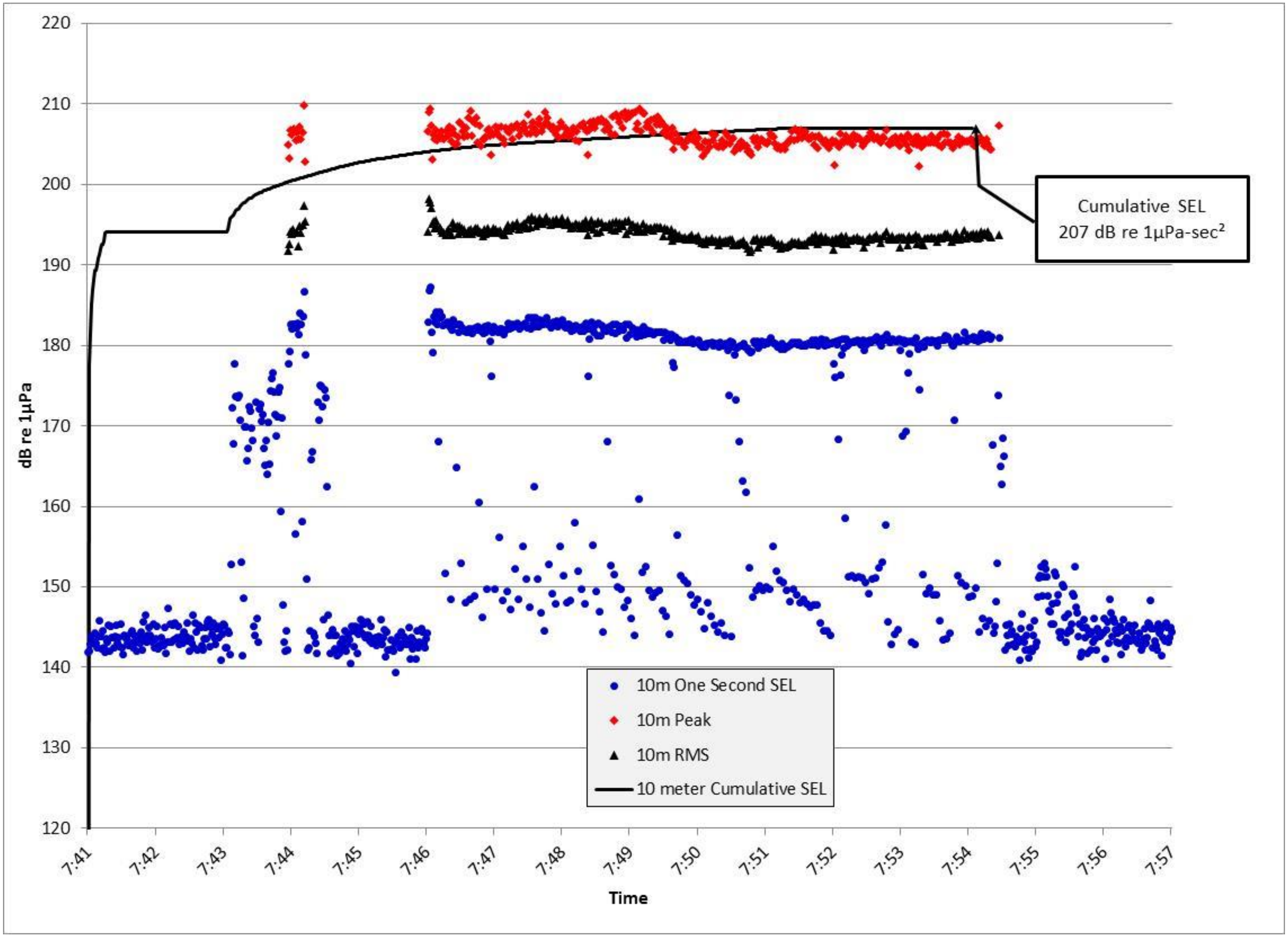

Figure-A-26. Underwater Noise Recorded at 33 Feet (10 Meters) ELCAS Pile #2 at JEB Little Creek, 28 April 2016.

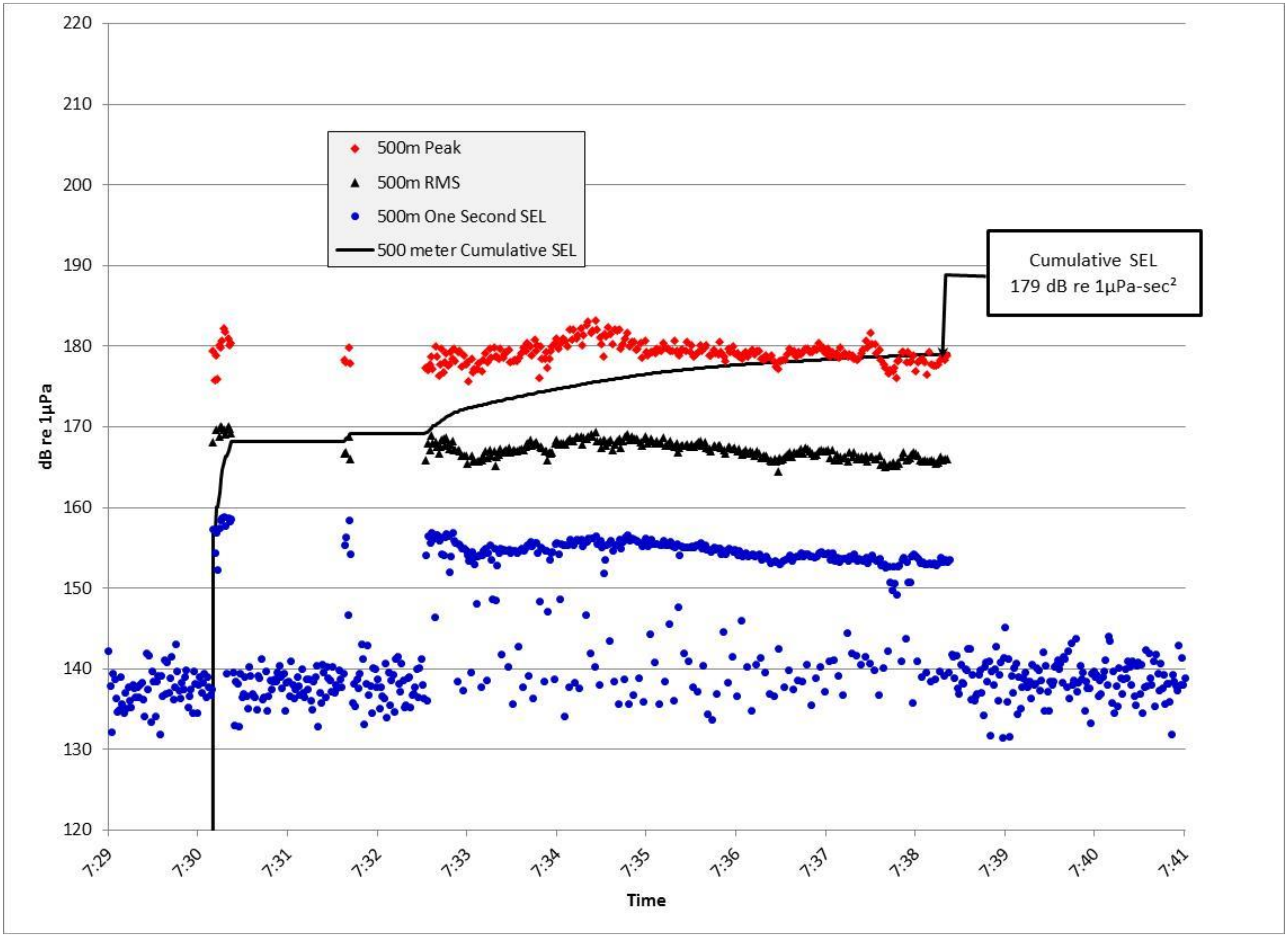

Figure A-27. Underwater Noise Recorded at 1,640 Feet (500 Meters) ELCAS Pile #1 at JEB Little Creek, 28 April 2016.

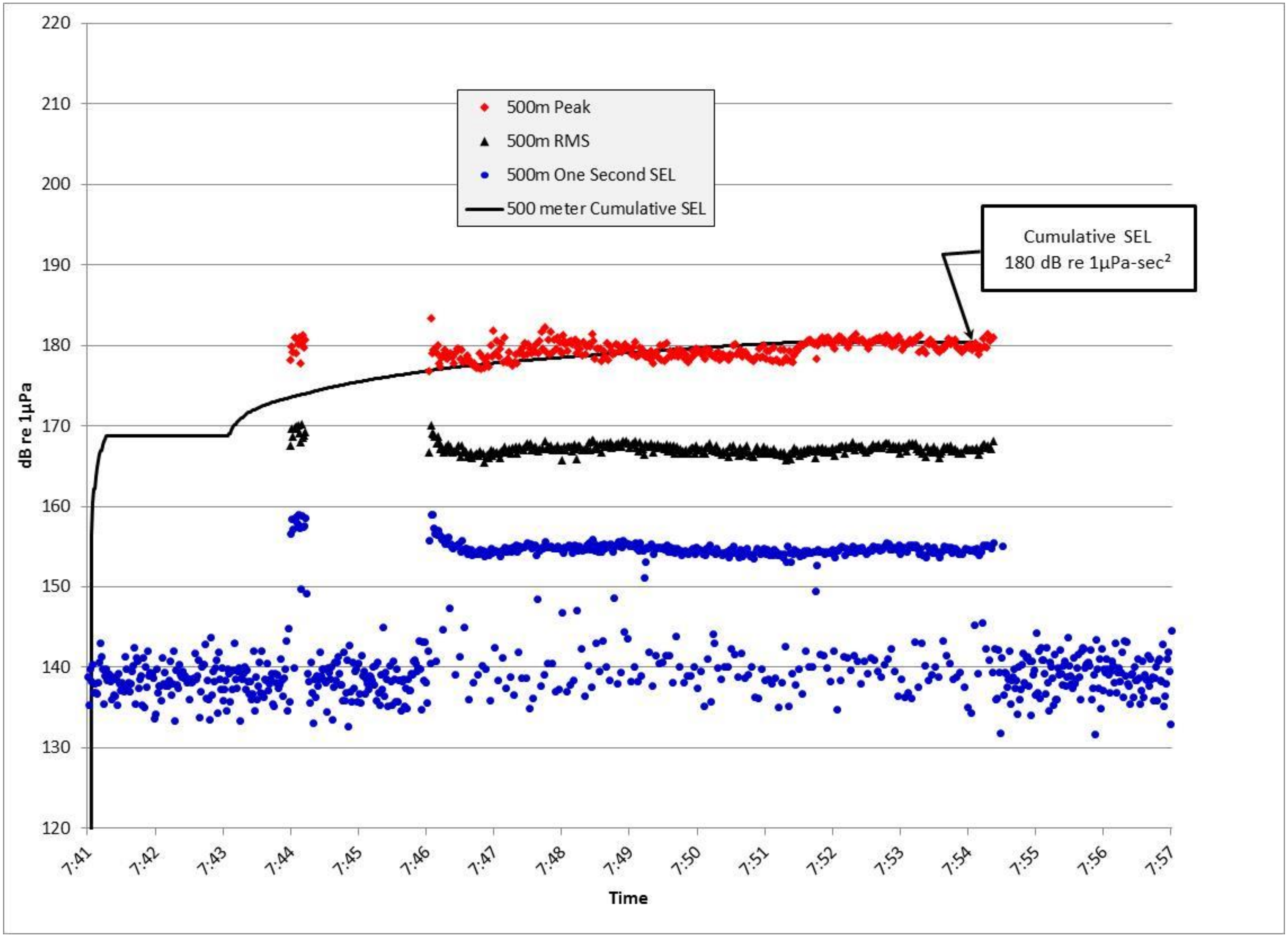

Figure A-28. Underwater Noise Recorded at 1,640 Feet (500 Meters) ELCAS Pile #2 at JEB Little Creek, 28 April 2016.

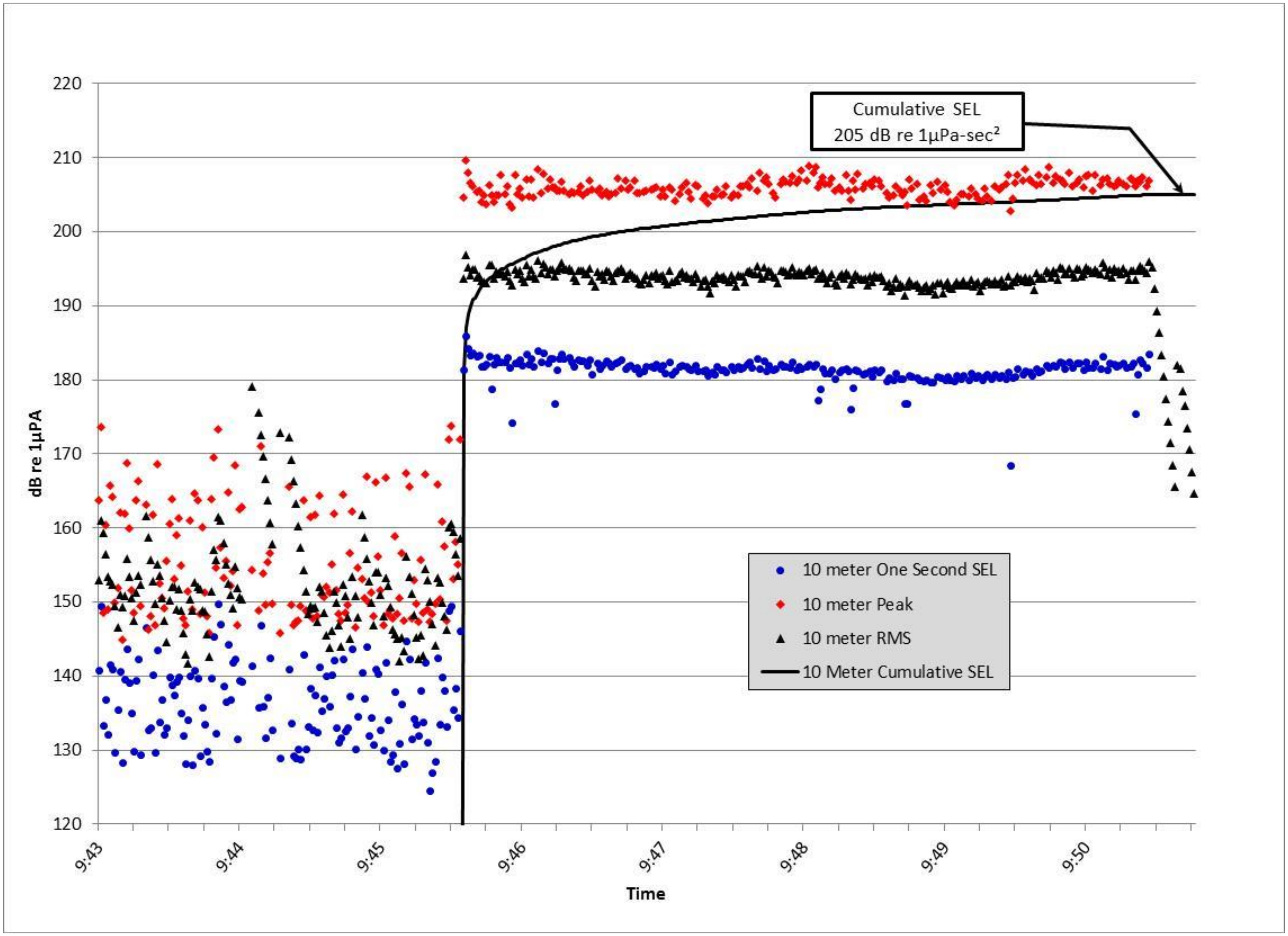

Figure A-29. Underwater Noise Recorded at 33 Feet (10 Meters) ELCAS Pile #3 at JEB Little Creek, 28 April 2016.

B

1/3 Octave Band Spectrum Data

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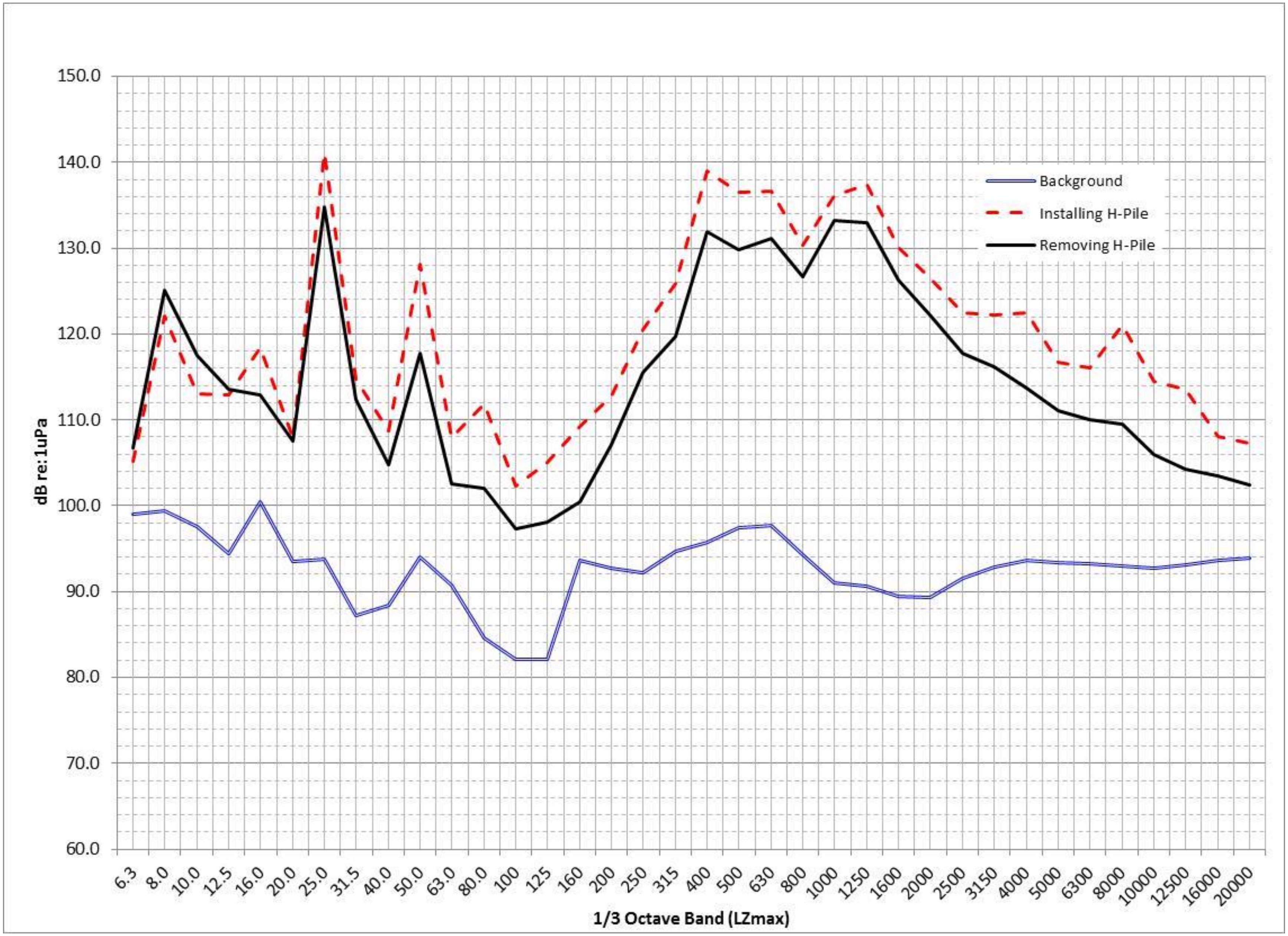

Figure B-1. 1/3 Octave Band Spectra for Installation and Removal of H-Piles with a Vibratory Hammer 28 May, 2013

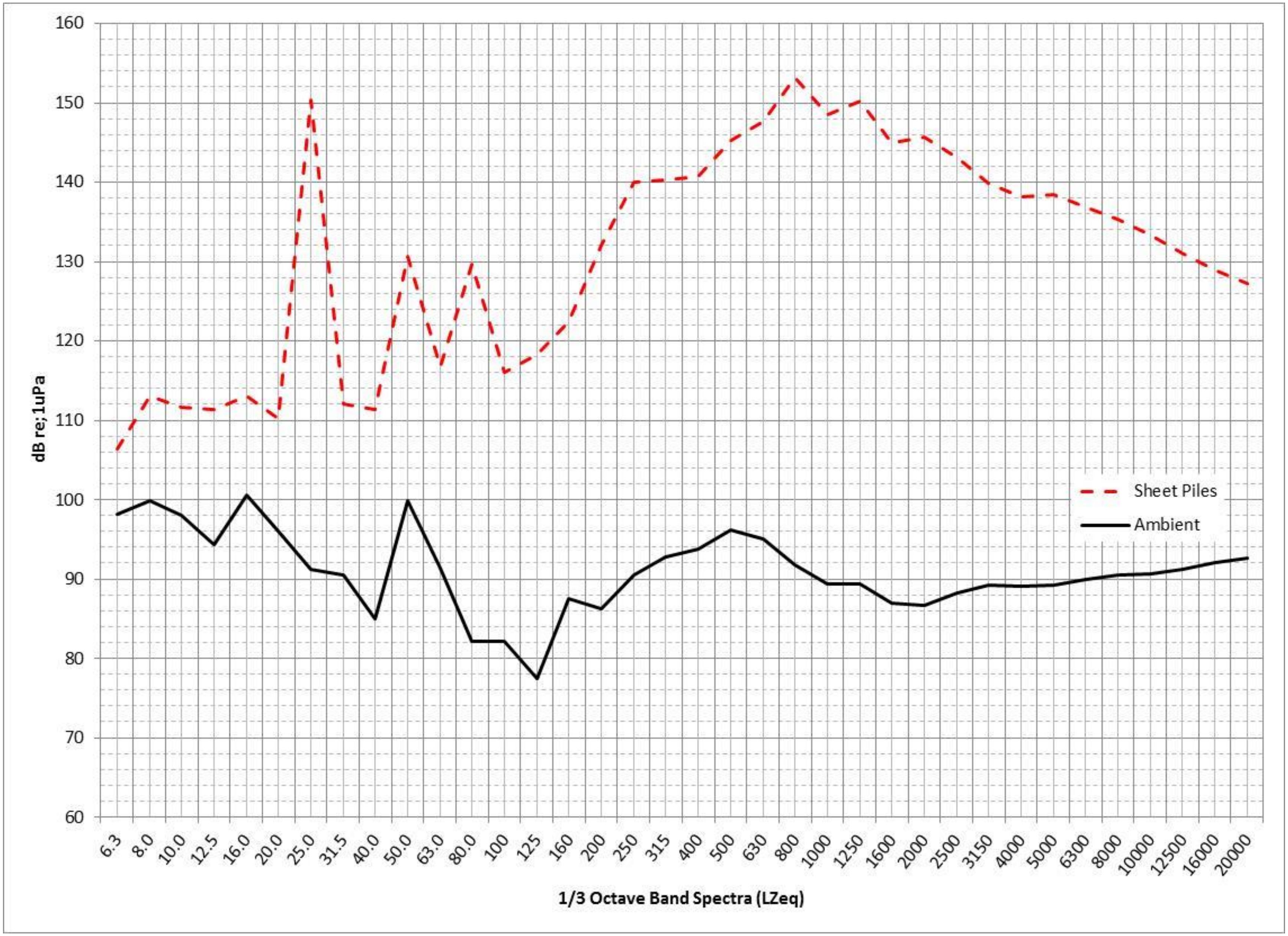

Figure B-2. Sheet Piles with Vibratory Hammer 28 May, 2013

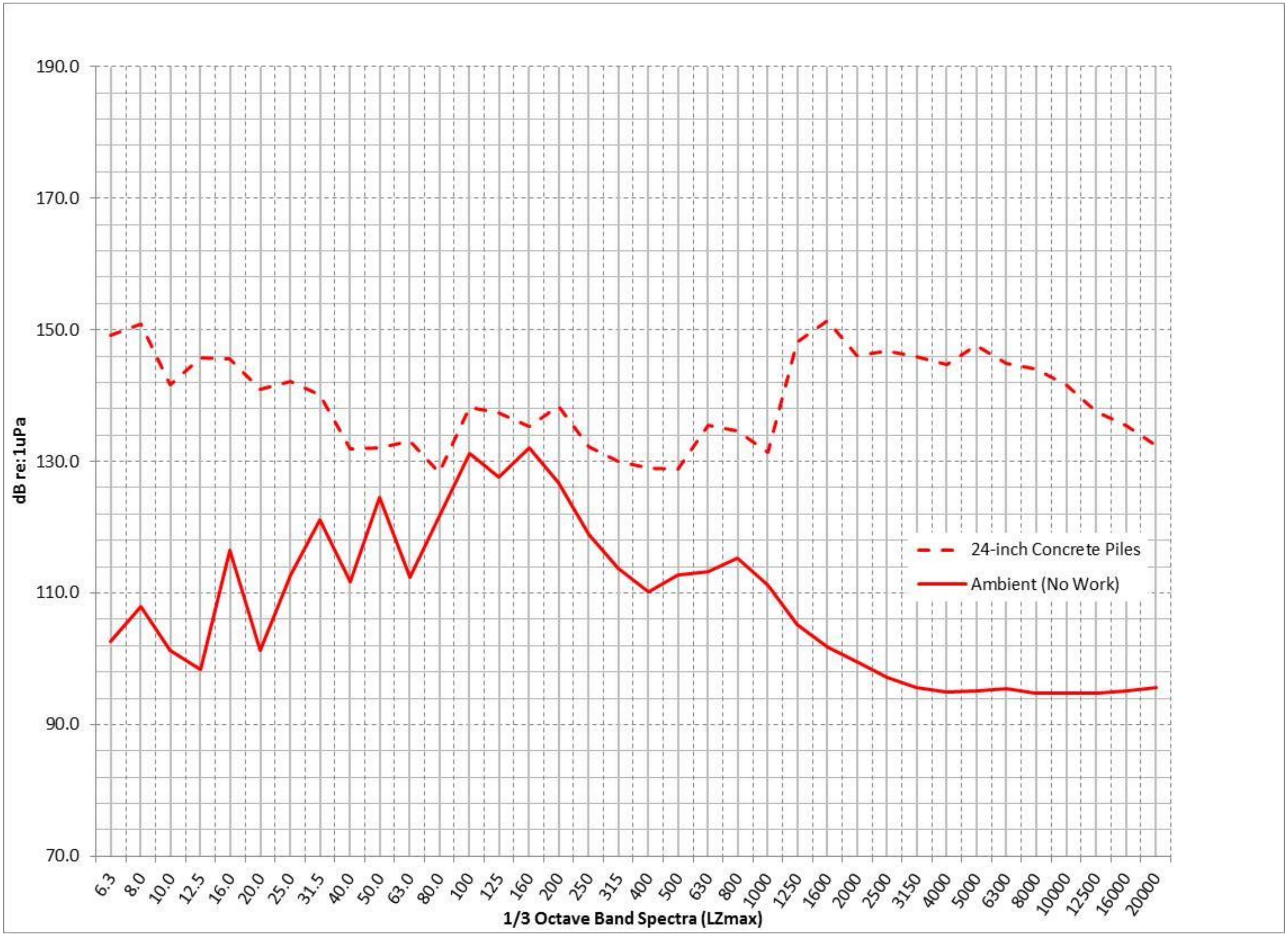

Figure B-3. 24-inch Concrete Piles with Diesel Impact Hammer 29, May, 2013

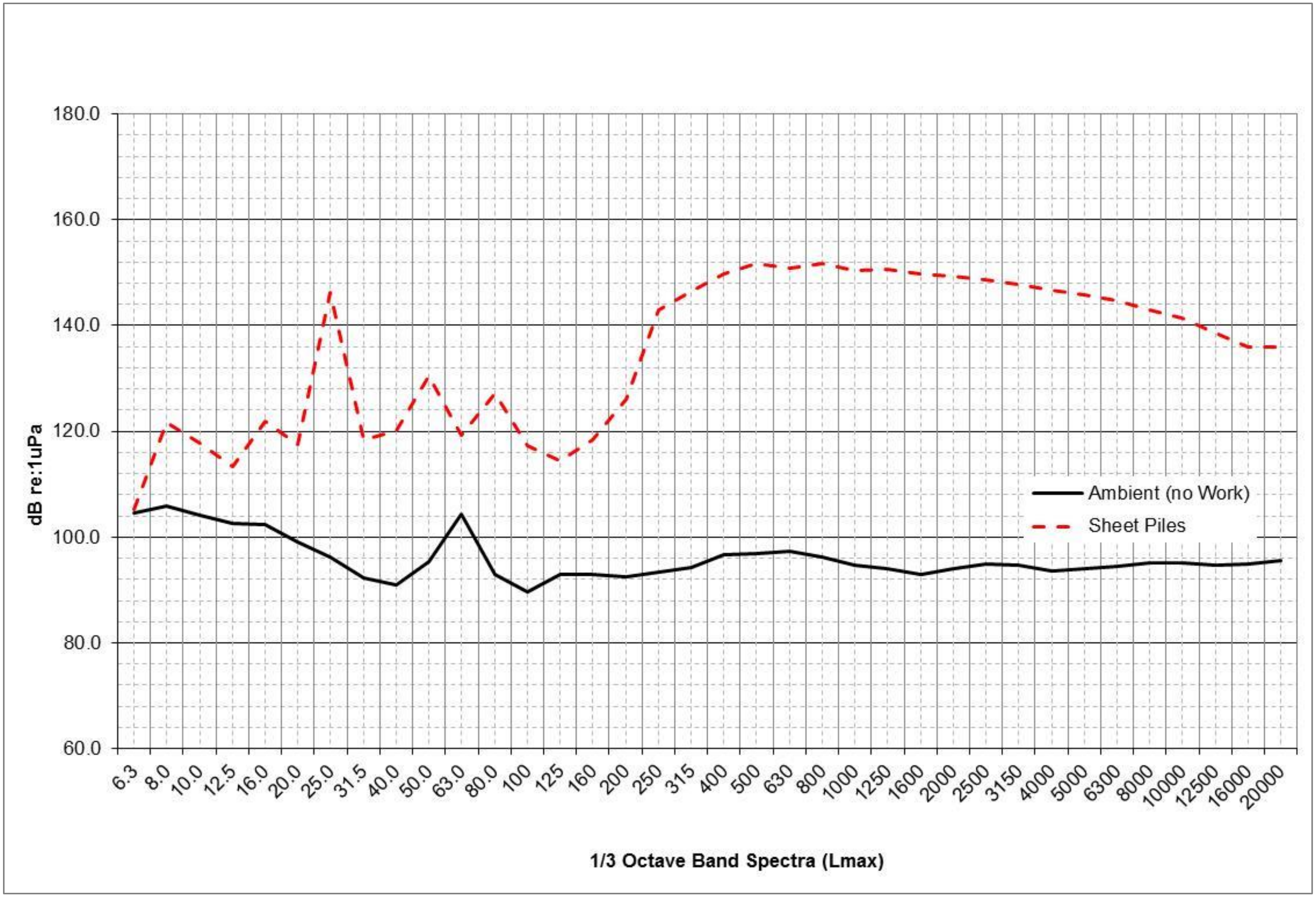

Figure B-4. Sheet Piles with Vibratory Hammer 30, May, 2013

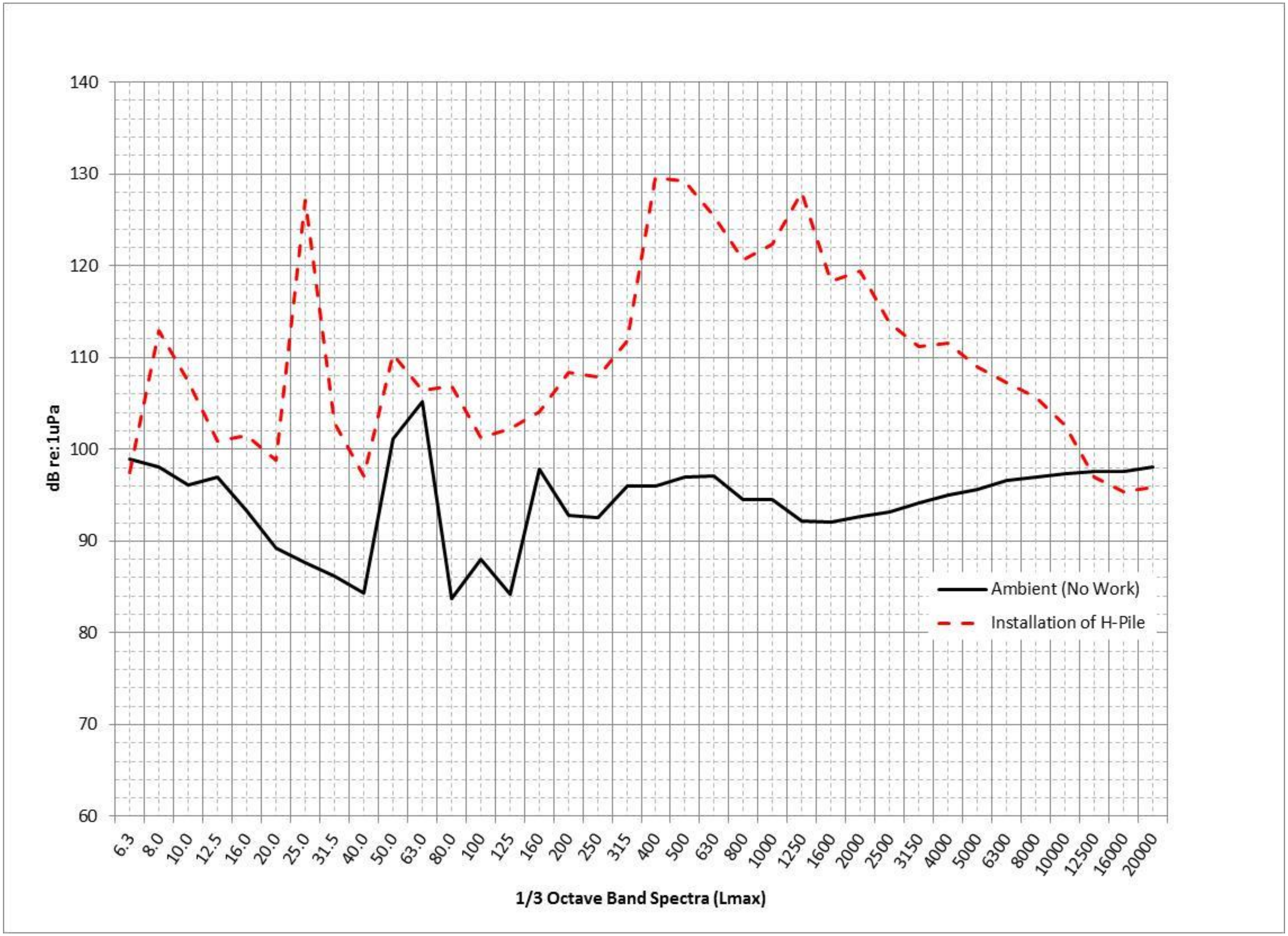

Figure B-5. H-Piles with Vibratory Hammer 30, May, 2013

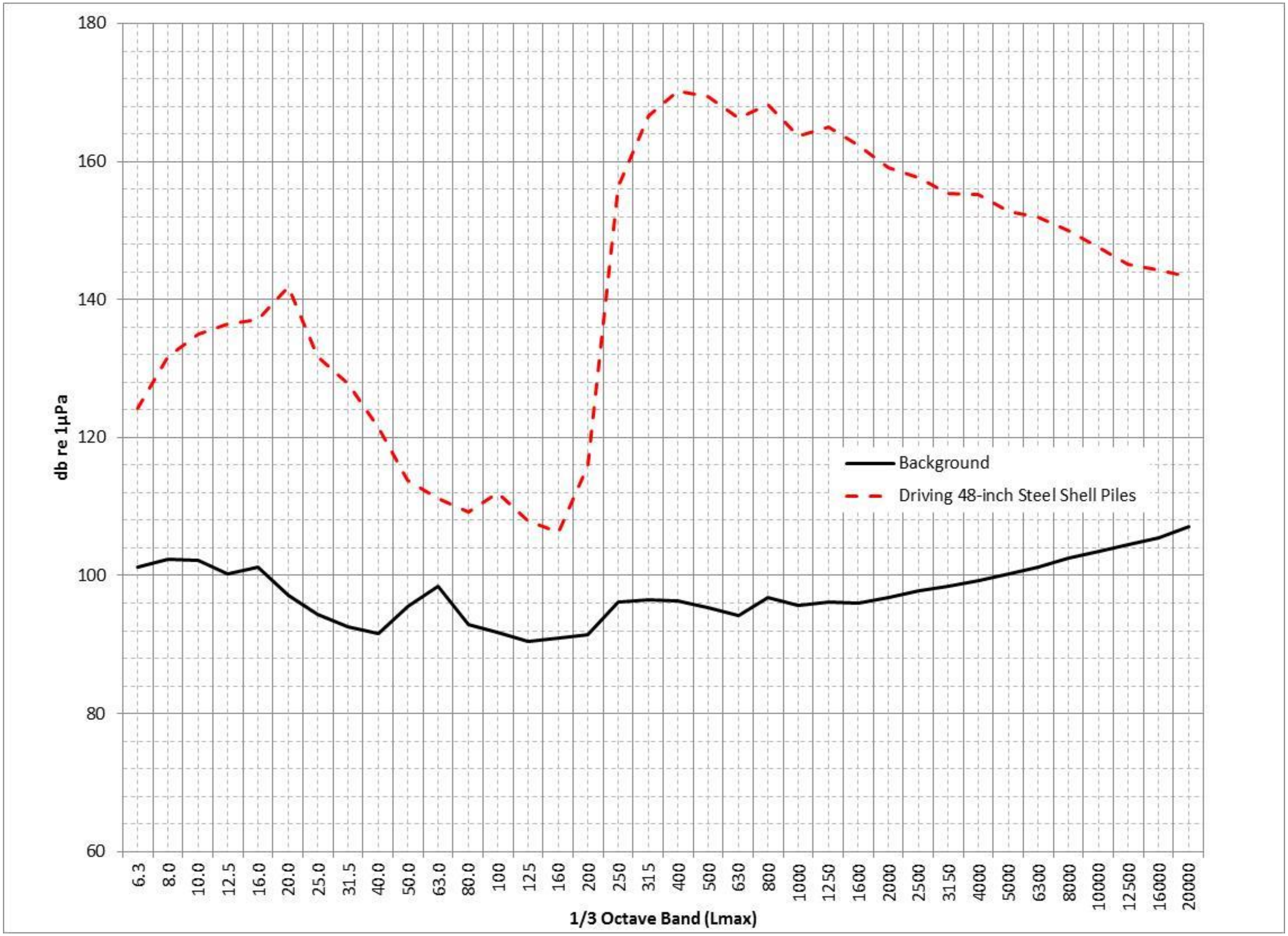

Figure B-6. 48-inch Steel Shell Piles with Diesel Impact Hammer 30, May, 2013

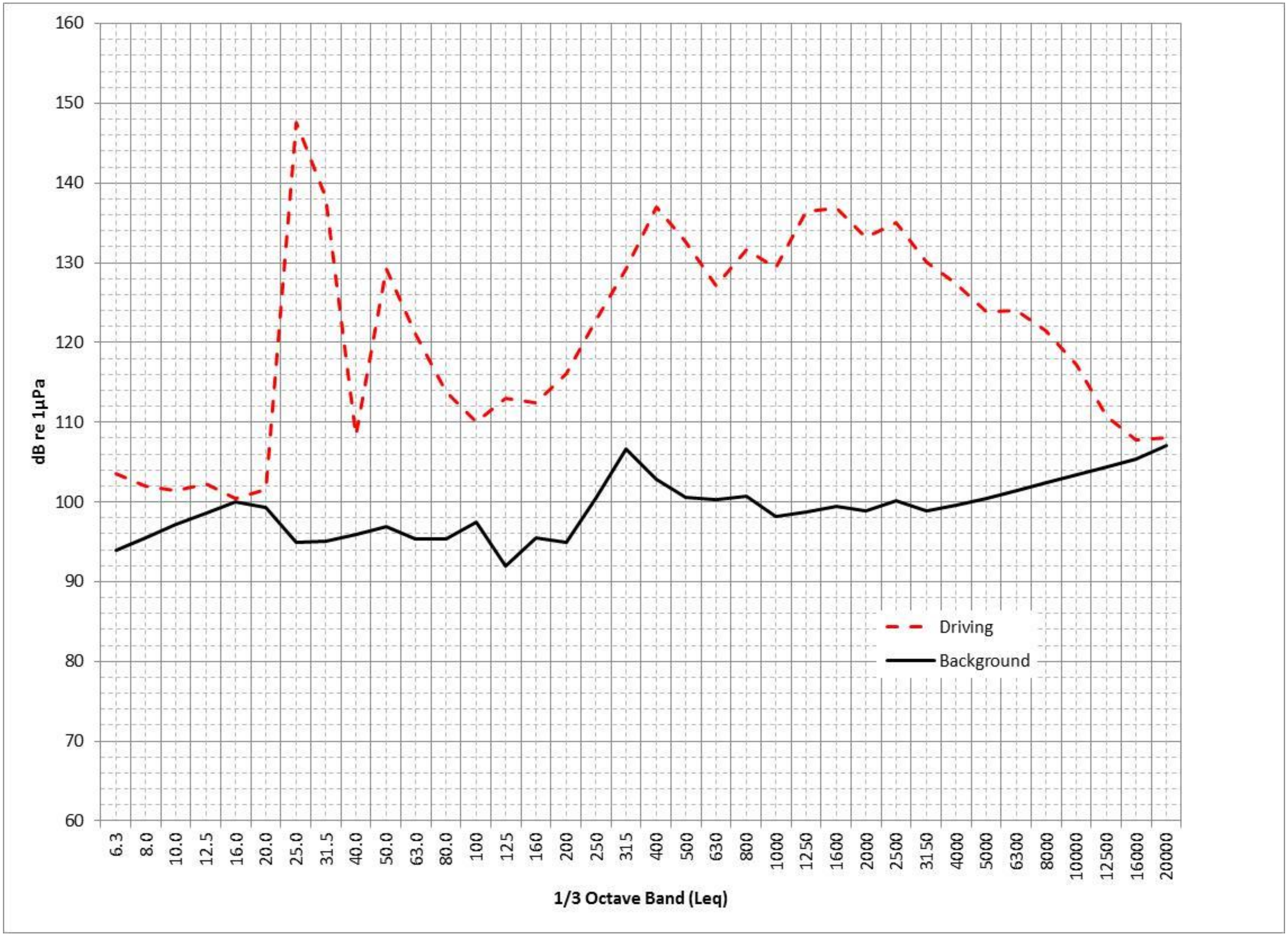

Figure B-7. 36-inch Steel Shell Piles with Vibratory Hammer 1 October, 2014

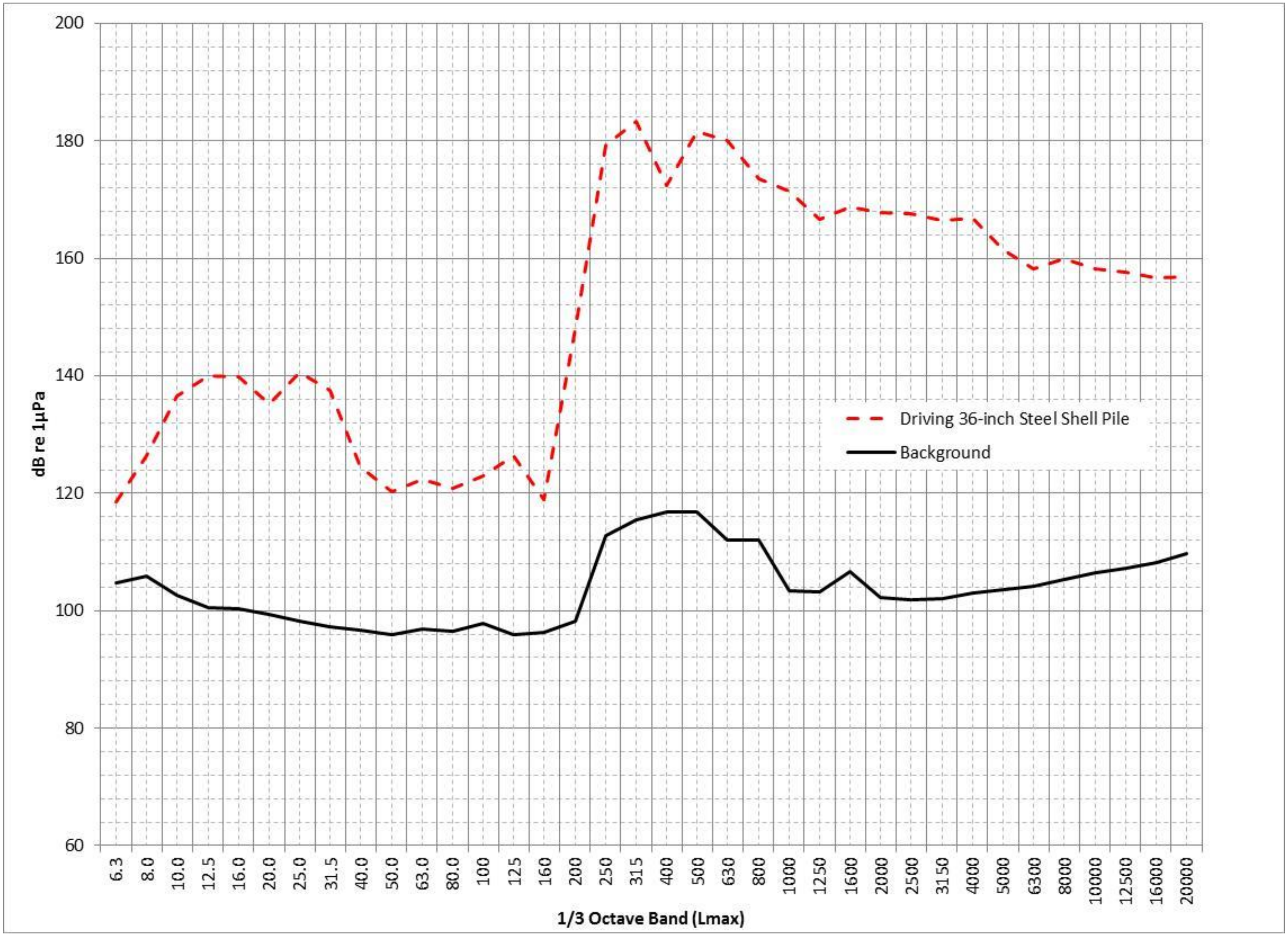

Figure B-8. 36-inch Steel Shell Piles with Diesel Impact Hammer 2 October, 2014

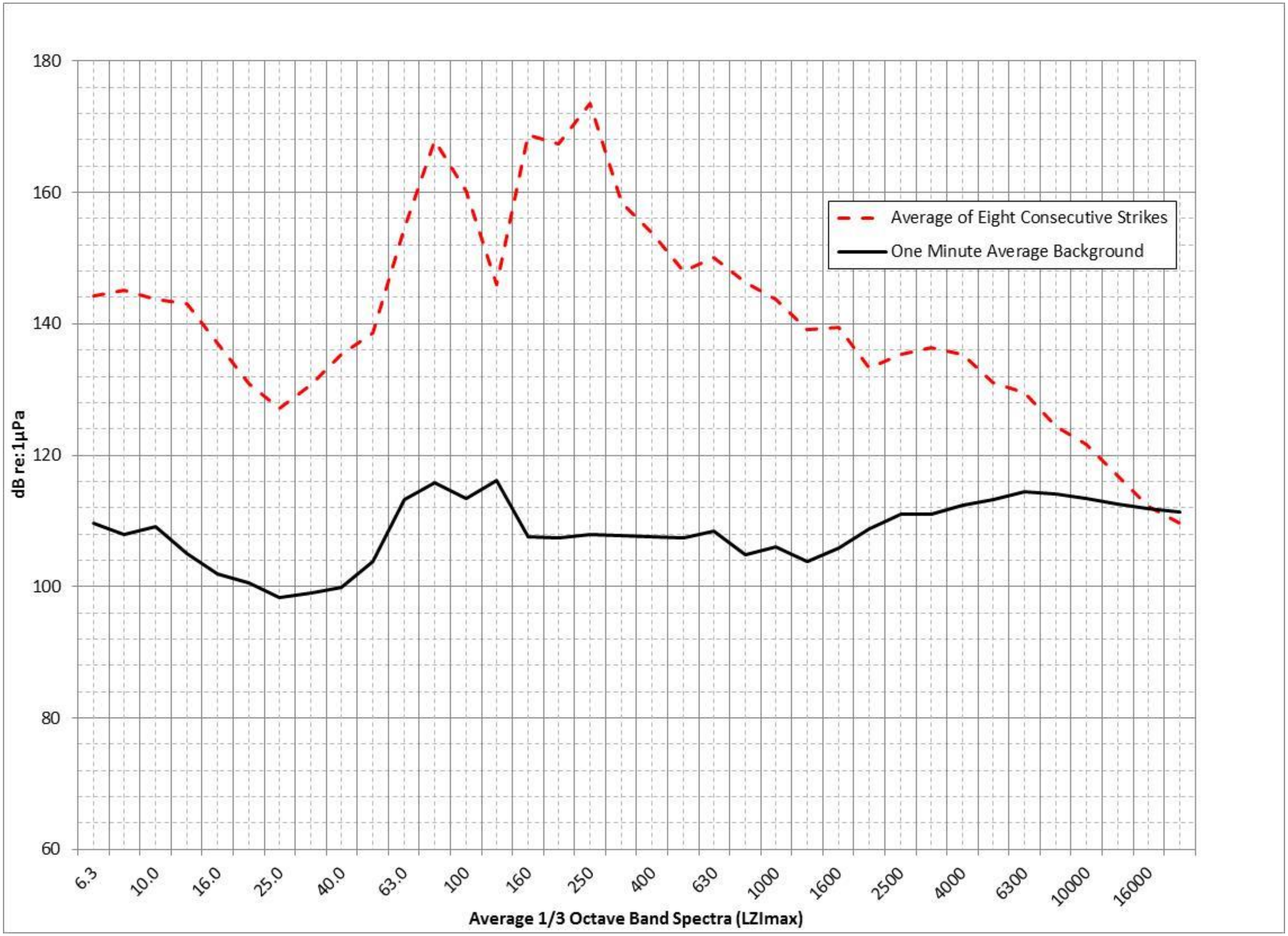

Figure B-9. Concrete Piles with Pneumatic Impact Hammer 25 October, 2014

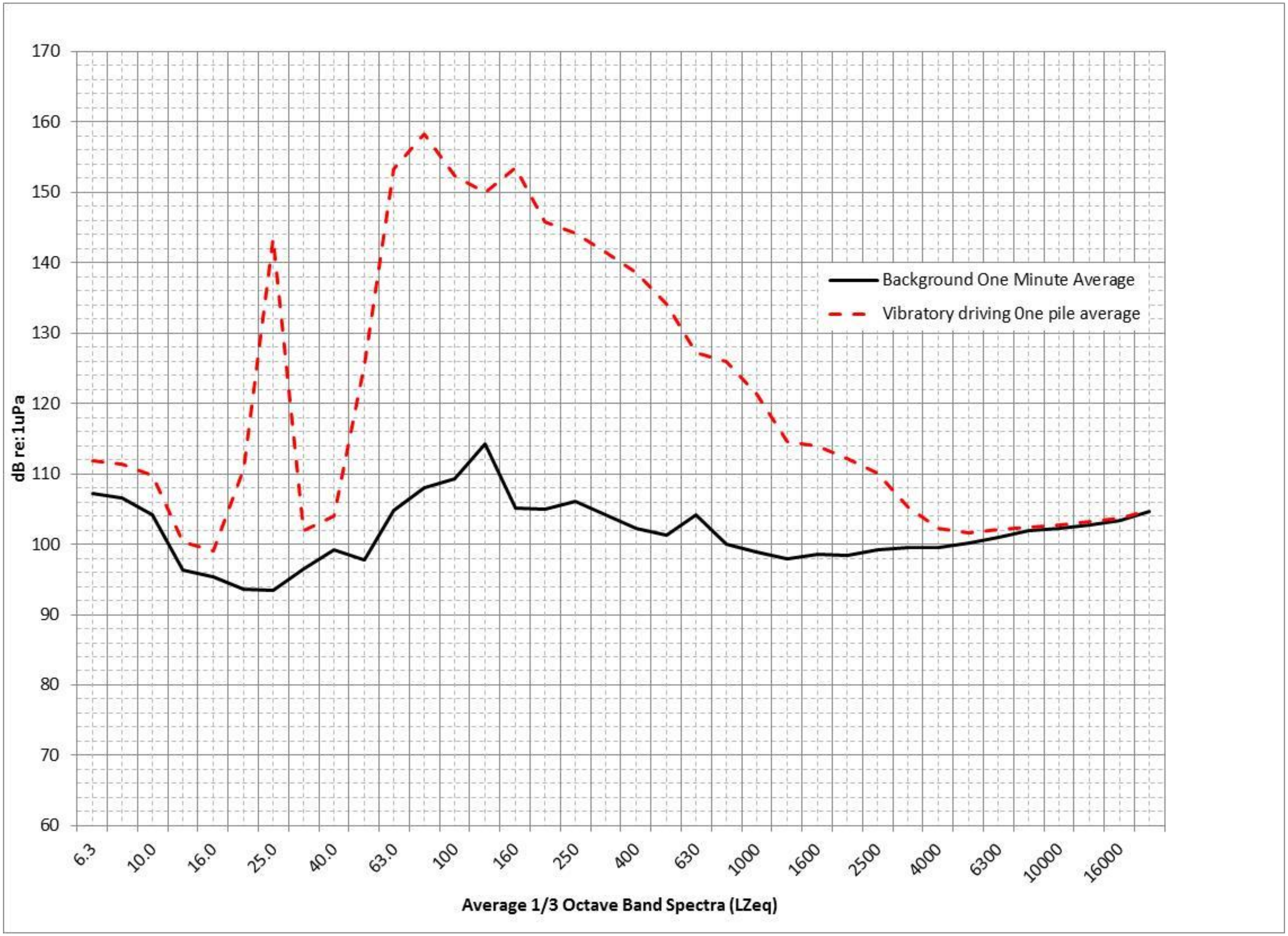

Figure B-10. Timber Piles with Vibratory Hammer 27 October 2014

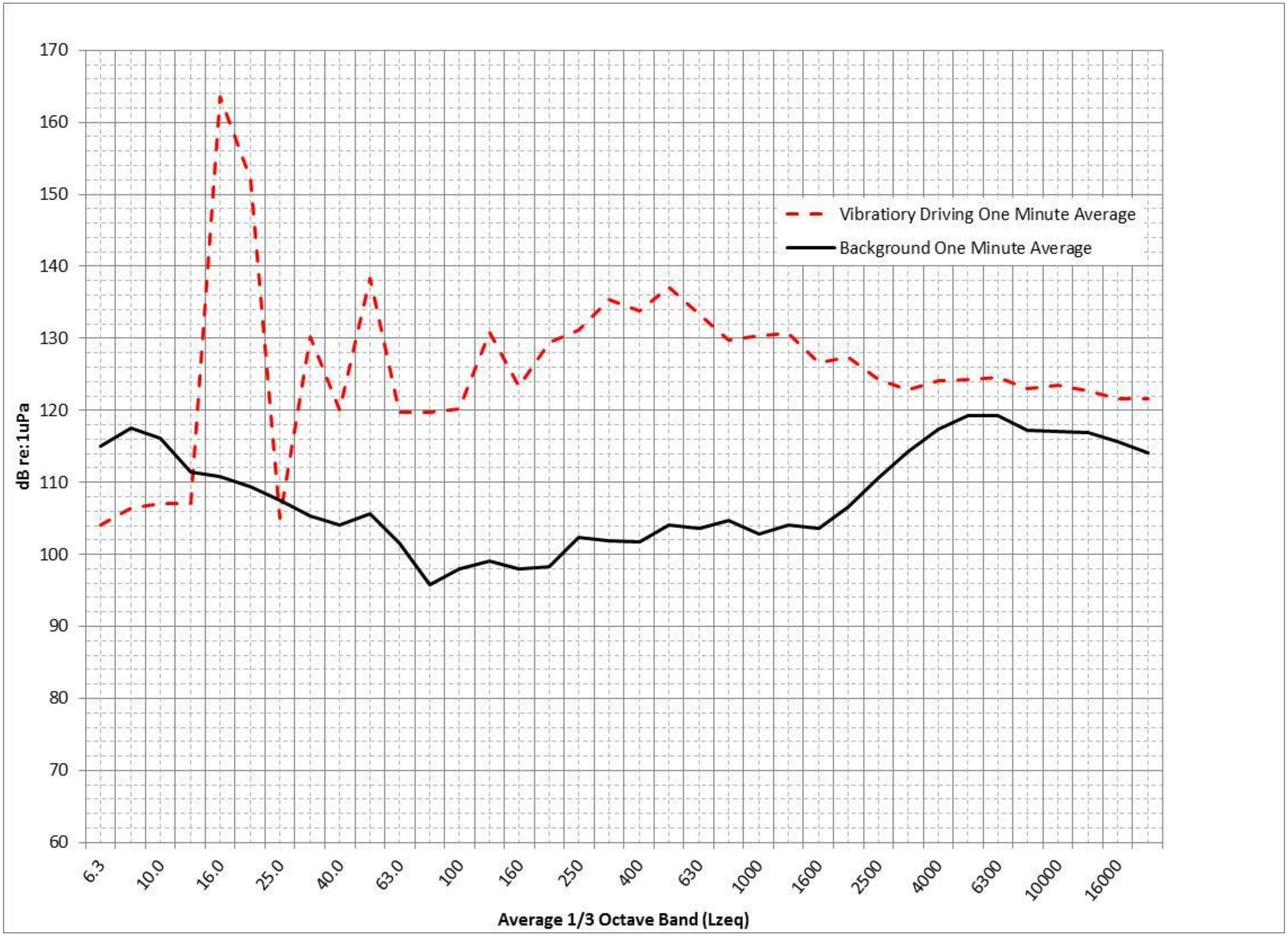

Figure B-11. King Piles with Vibratory Hammer 09 June, 2015

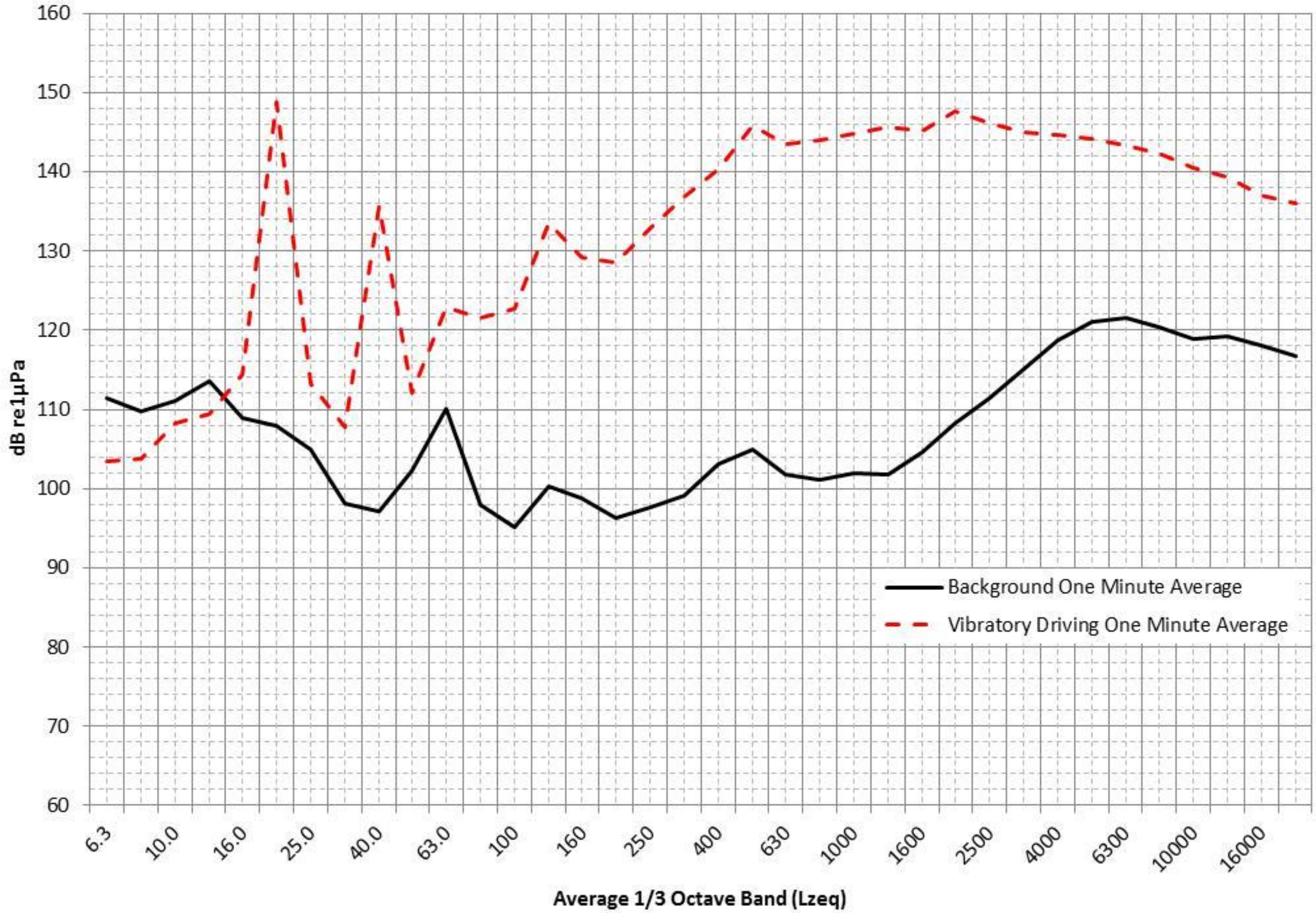

Figure B-12. Sheet Piles with Vibratory Hammer 09 June 2015

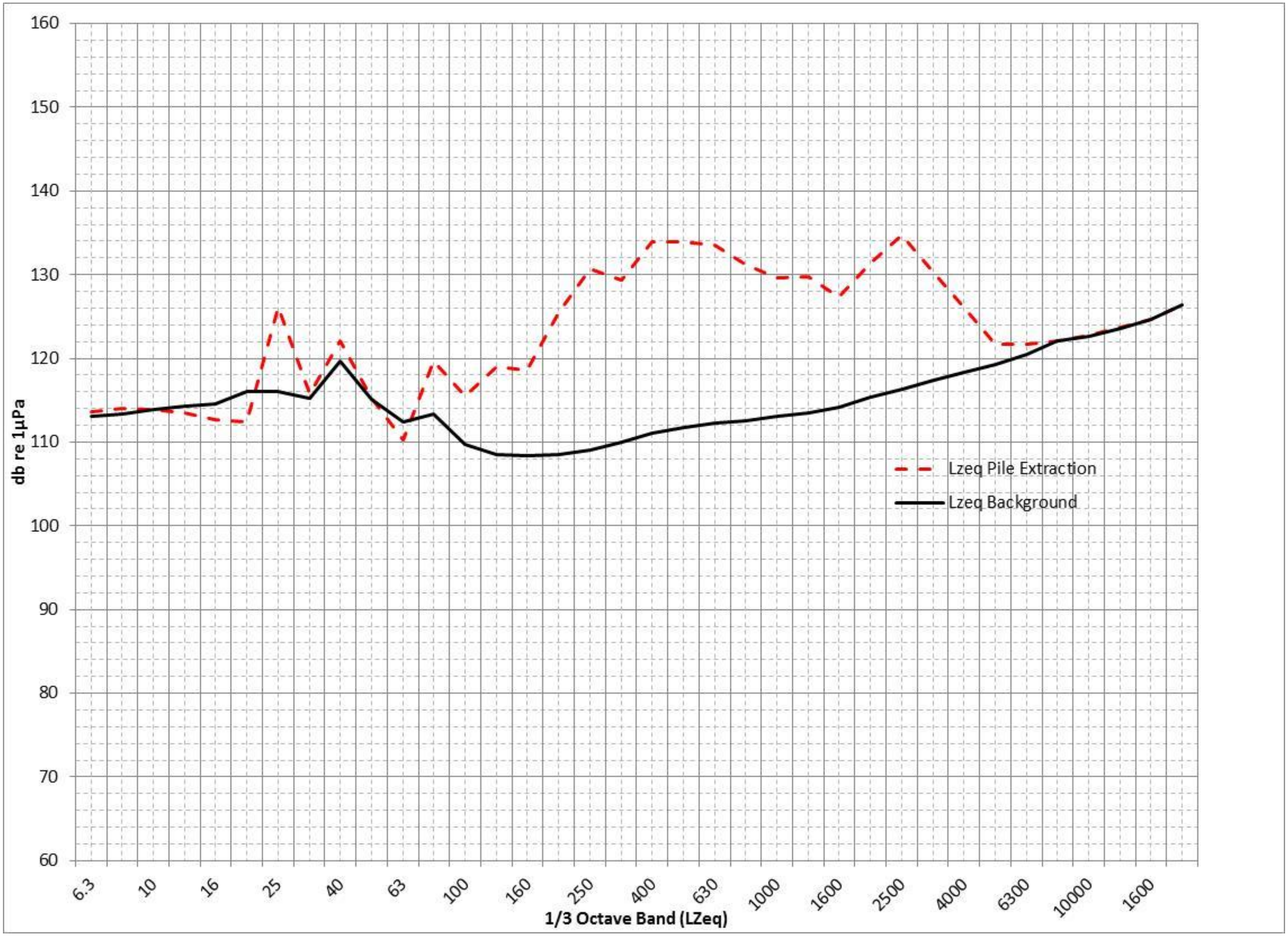

Figure B-13. Removing 24-inch Steel Shell Piles with Vibratory Hammer 10 September 2015

Figure B-14. 24-inch Steel Shell Piles with Diesel Impact Hammer

C

C - Time History and 1-Minute Airborne Data

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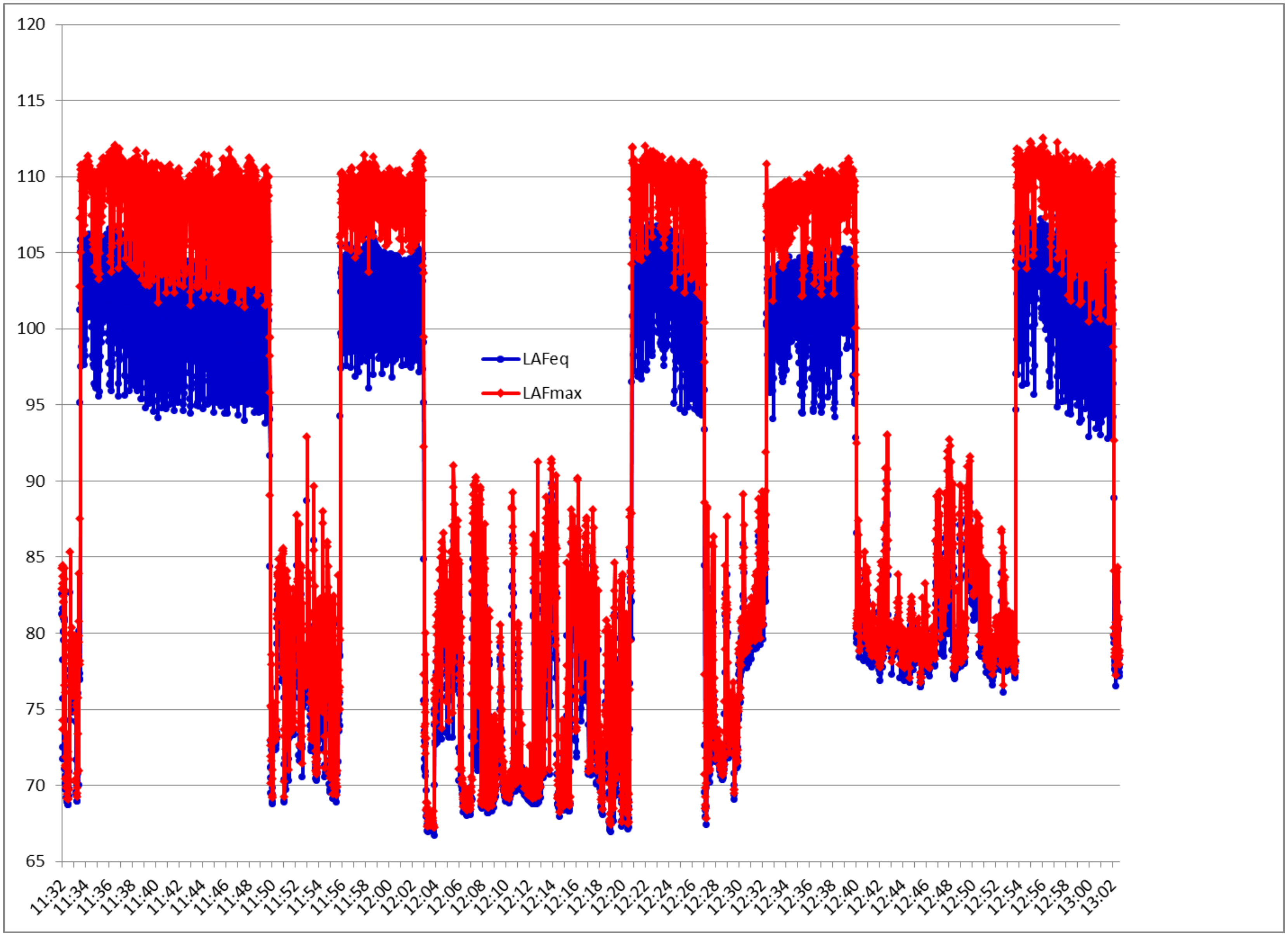

Figure C-1 – Airborne Noise SPLs – Impact Driving 48-inch Steel Shell Piles Philadelphia Naval Ship yard 30 September 2014 (one minute)

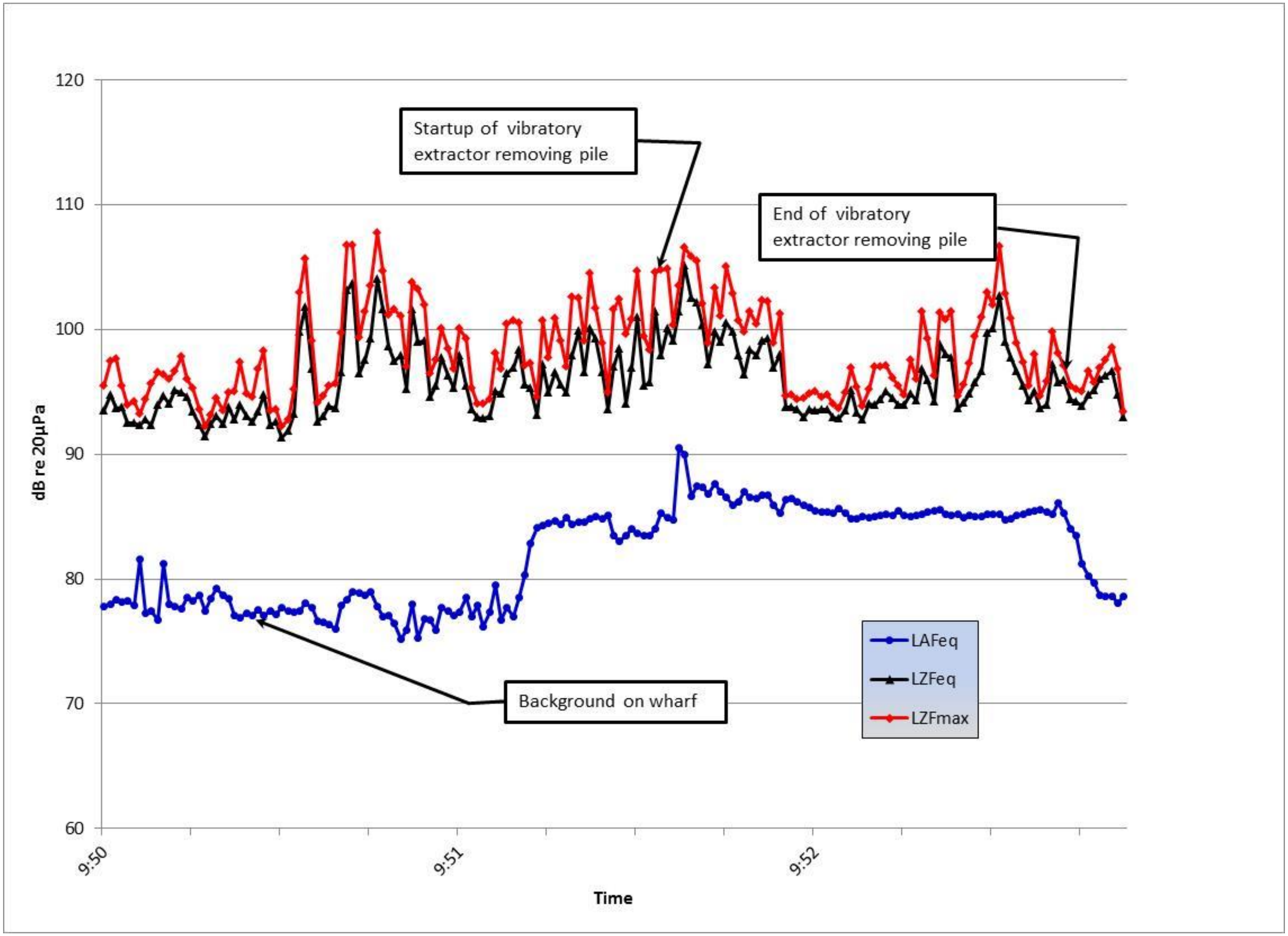

Figure C-2 – Airborne Noise SPLs – Vibratory Installation of 36-inch Steel Shell Piles Philadelphia Naval Ship yard 01 October 2014 (one Second)

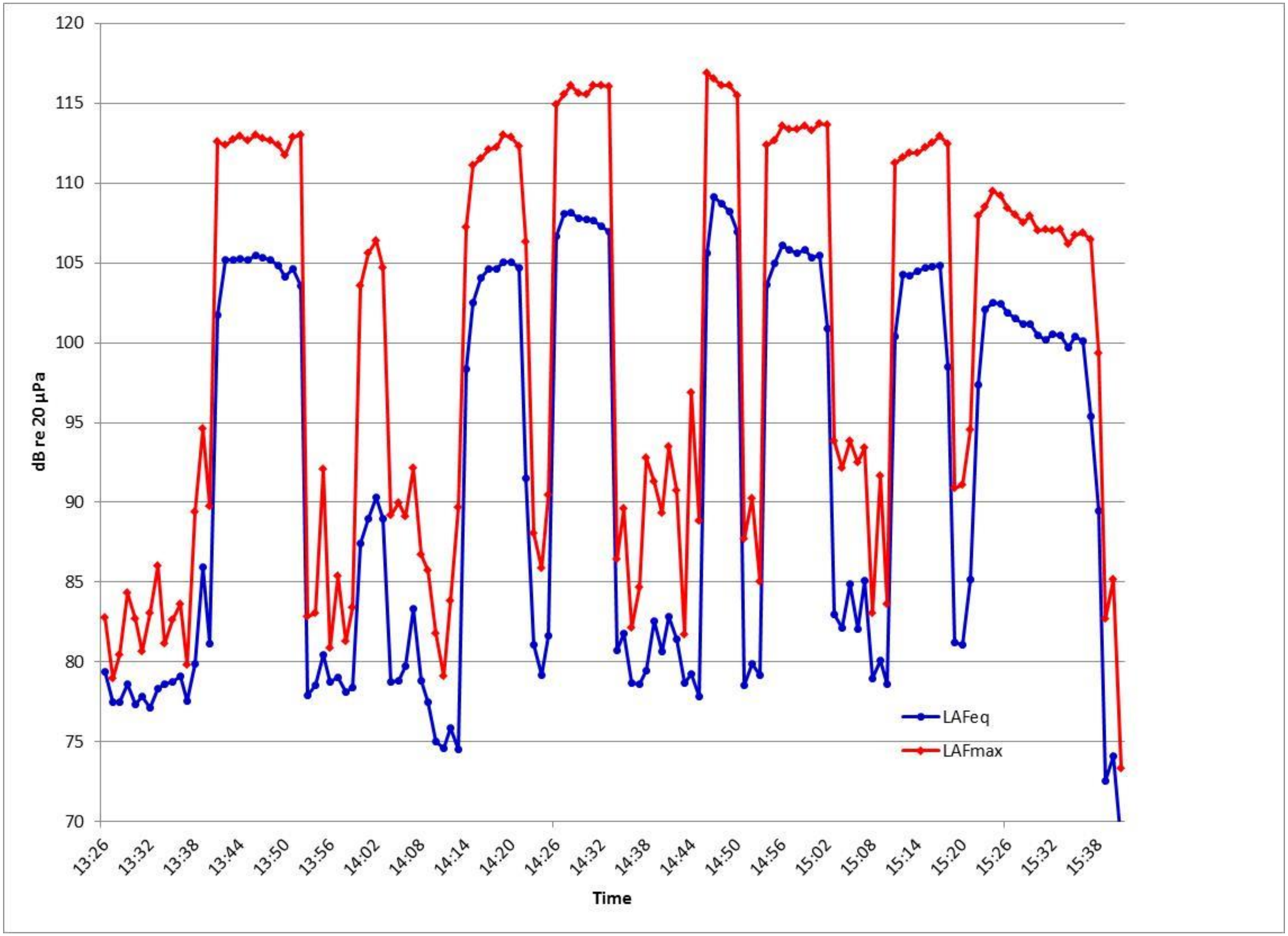

Figure C-3 – Airborne Noise SPLs – Impact Driving of 36-inch Steel Shell Piles Philadelphia Naval Ship yard 01 October 2014 (one-minute)

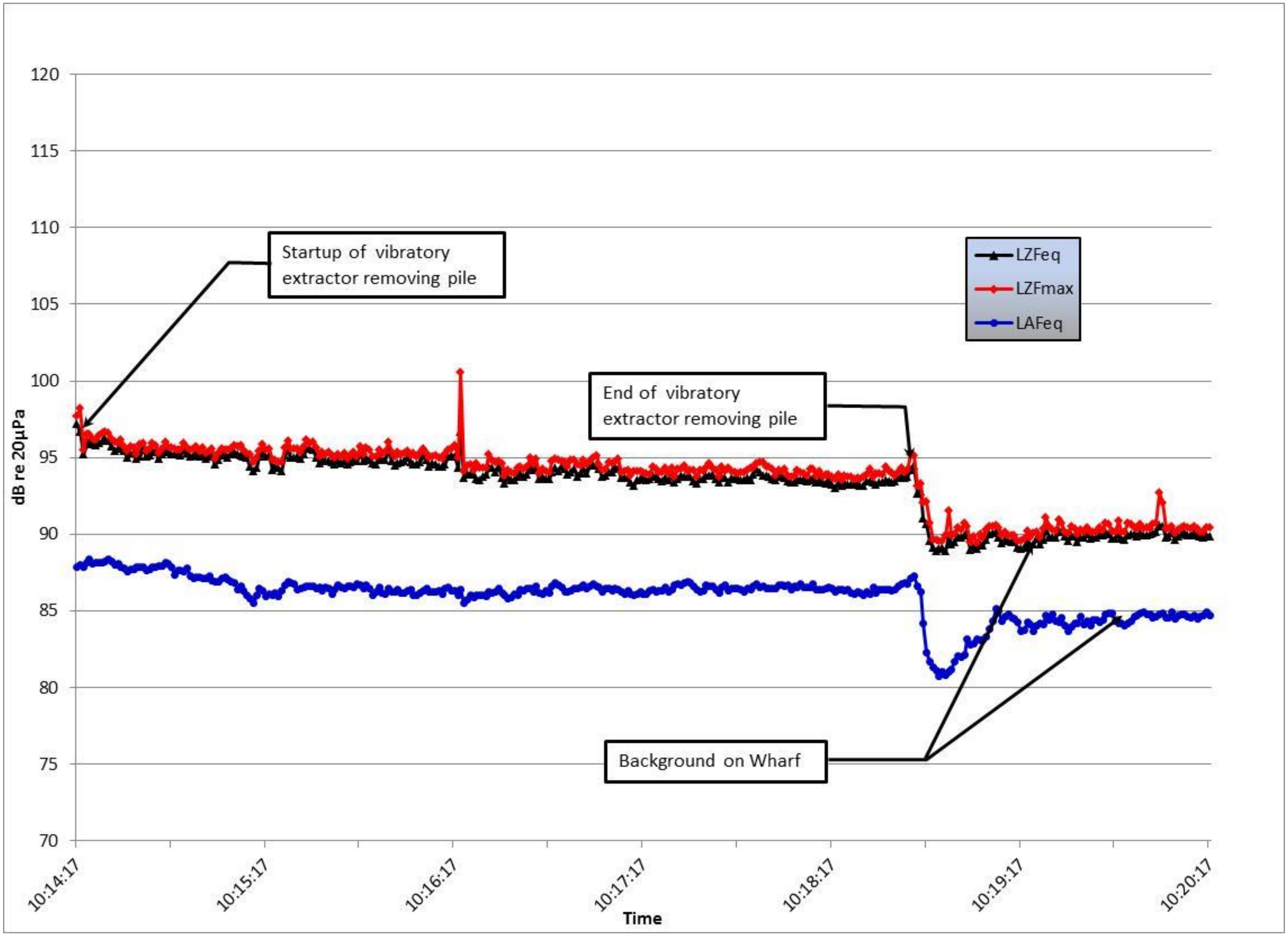

Figure C-4 – Pile 1 Airborne Noise SPLs Recorded During Removal of ELCS Pile #1 at JEB Little Creek, 10 September 2015.

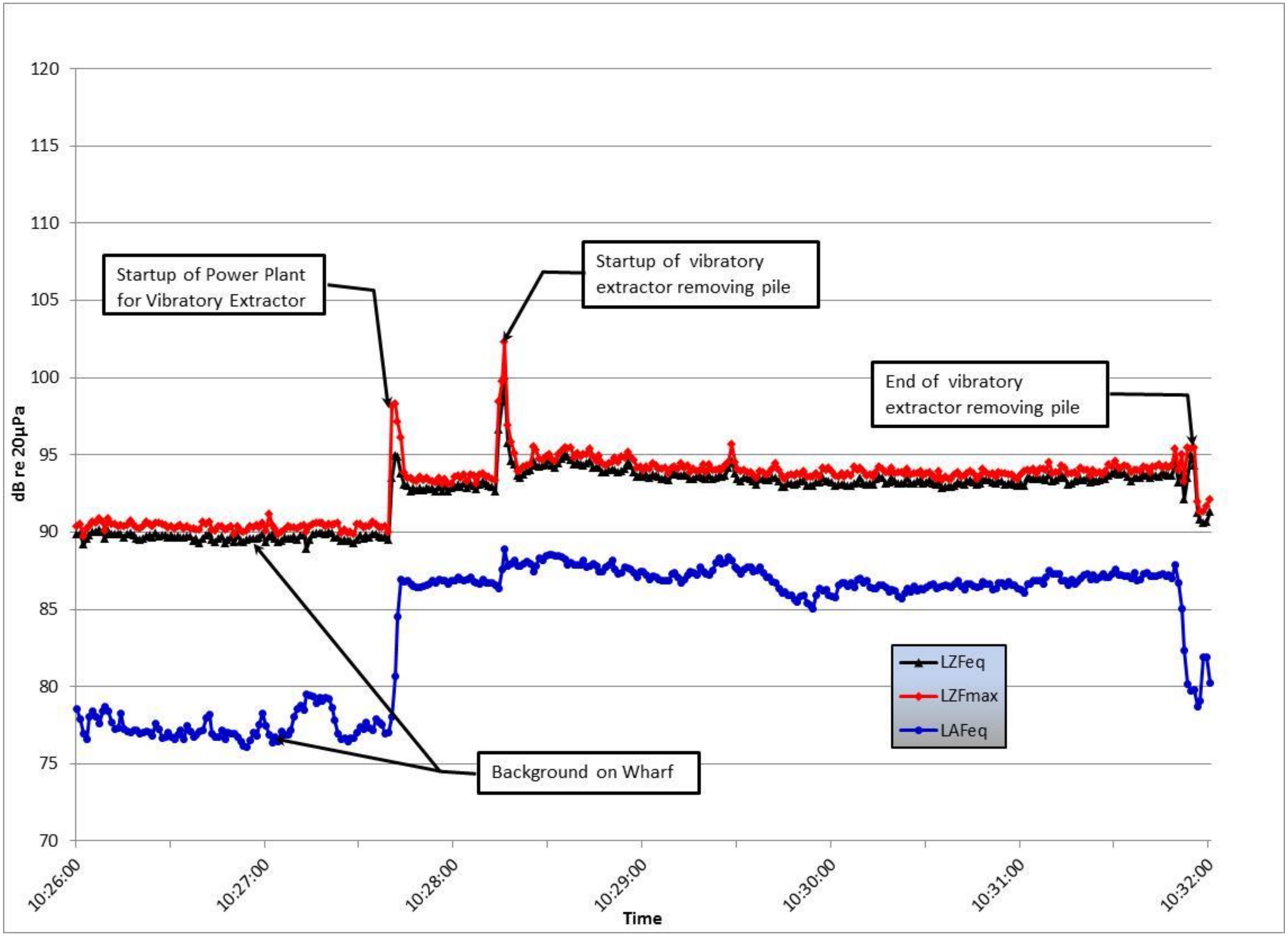

Figure C-5. Airborne Noise SPLs Recorded During Removal of ELCS Pile #2 at JEB Little Creek, 10 September 2015.

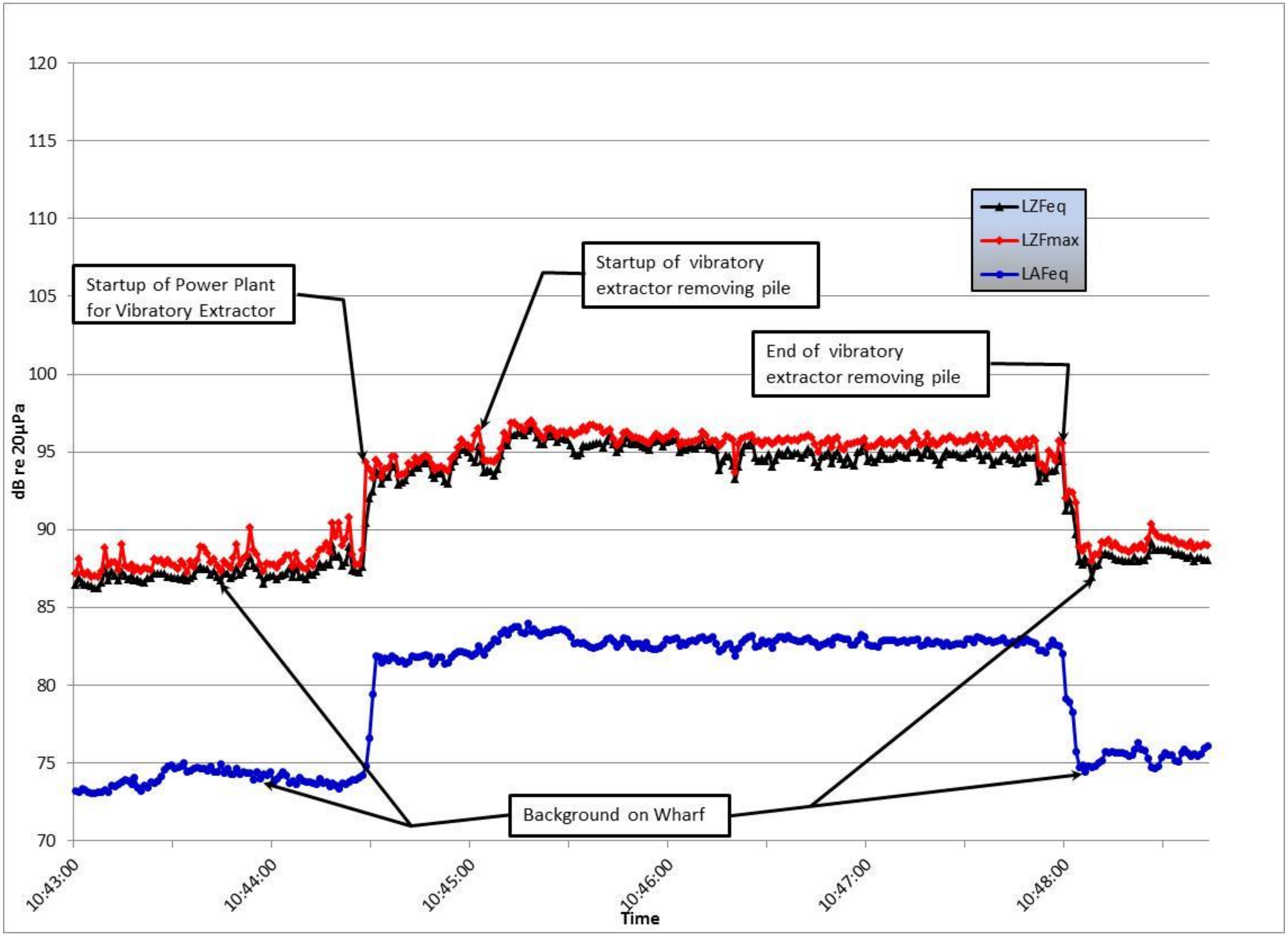

Figure C-6. Airborne Noise SPLs Recorded During Removal of ELCS Pile #3 at JEB Little Creek, 10 September 2015.

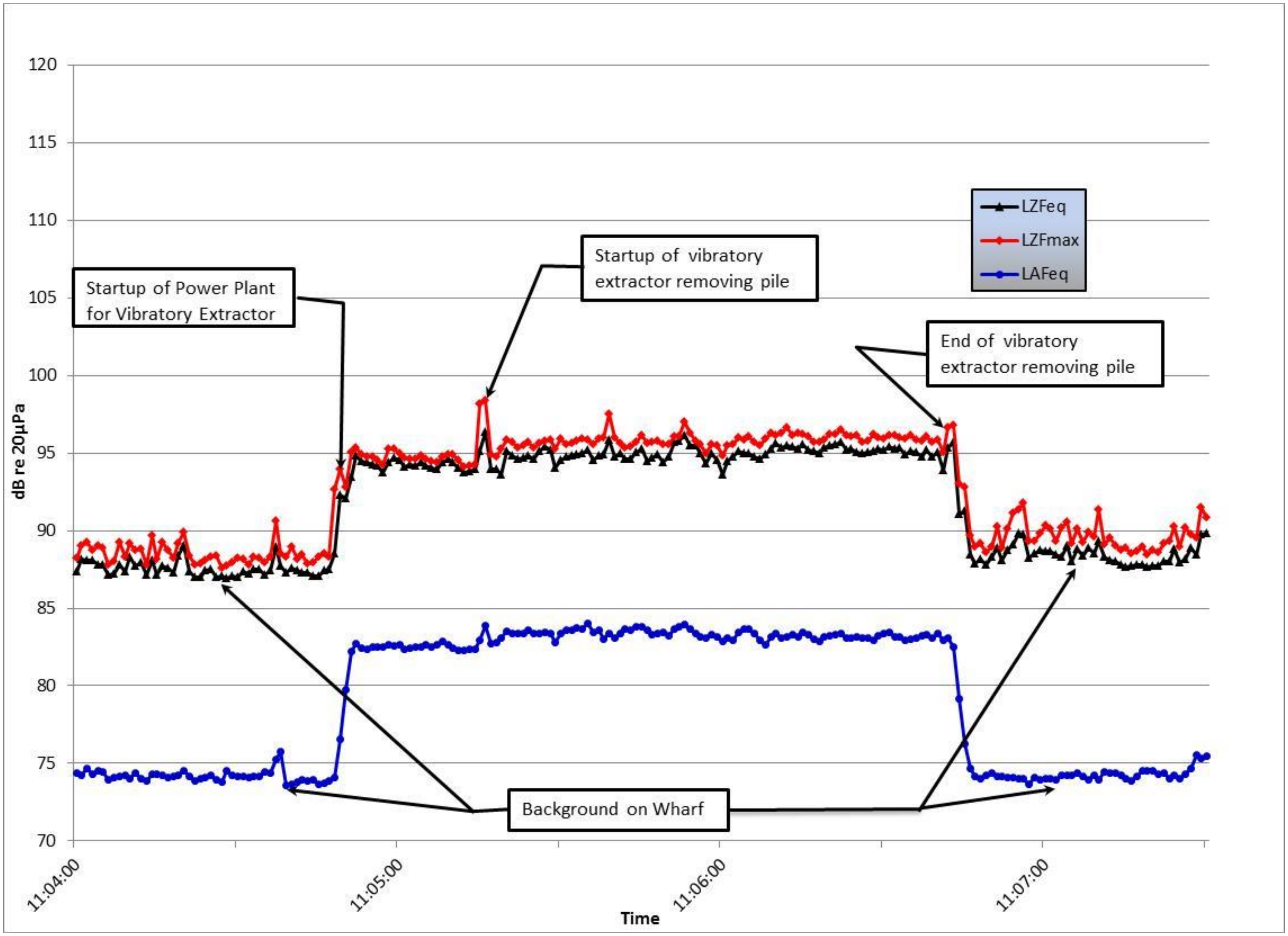

Figure C-7. Airborne Noise SPLs Recorded During Removal of ELCS Pile #4 at JEB Little Creek, 10 September 2015.

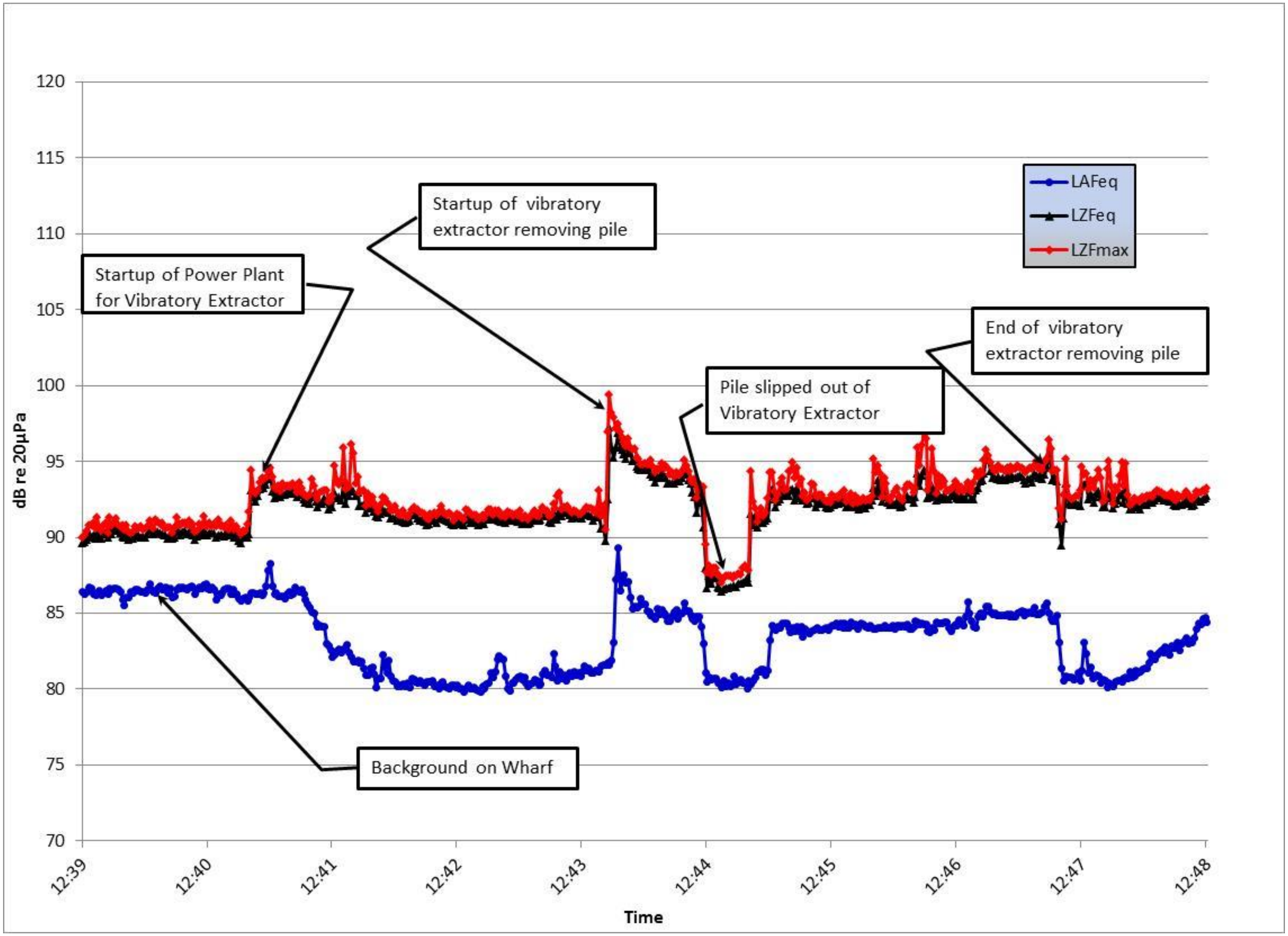

Figure C-8. Airborne Noise SPLs Recorded During Removal of ELCS Pile #6 at JEB Little Creek, 10 September 2015.

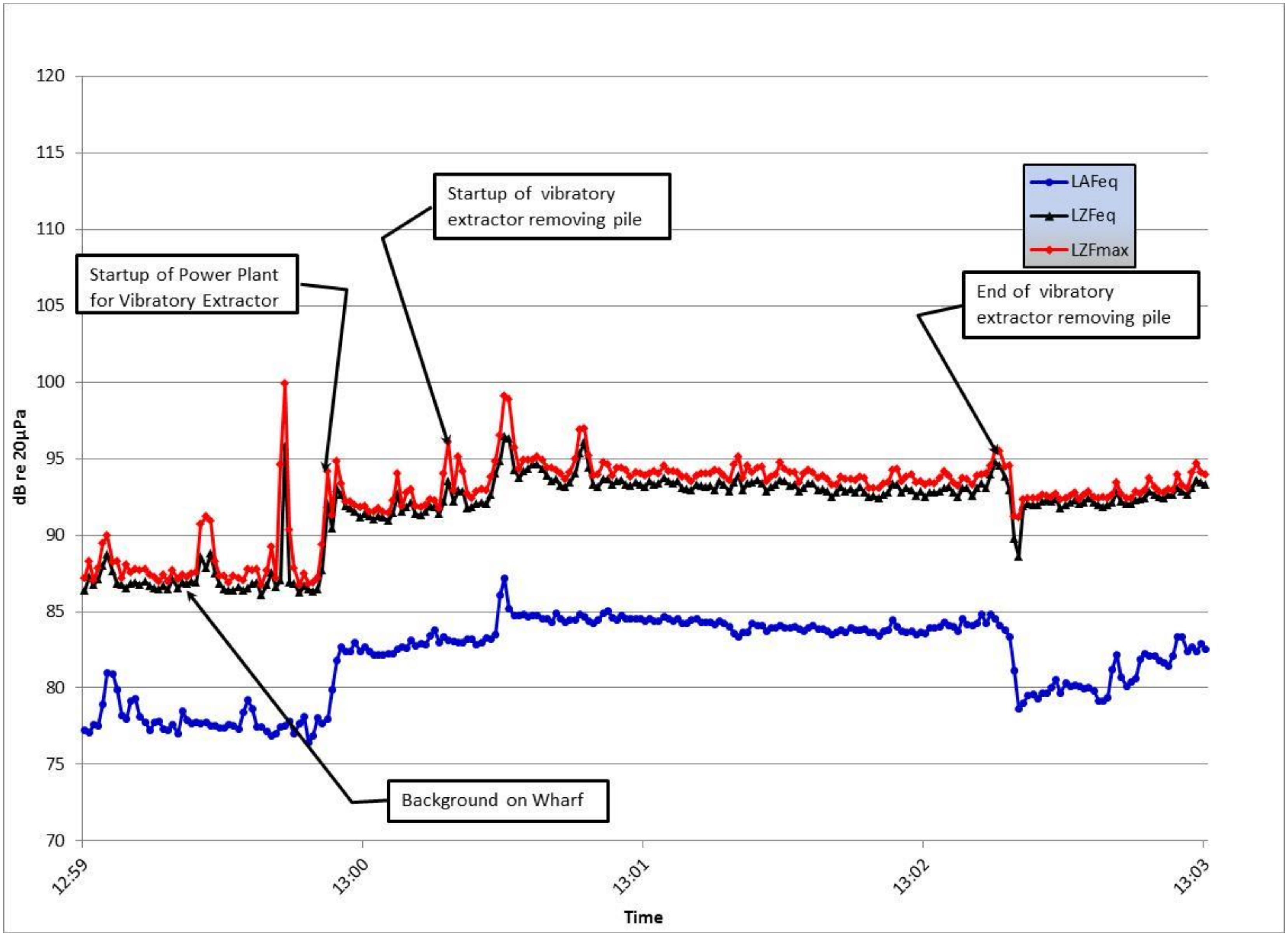

Figure C-9. Airborne Noise SPLs Recorded During Removal of ELCS Pile #7 at JEB Little Creek, 10 September 2015.

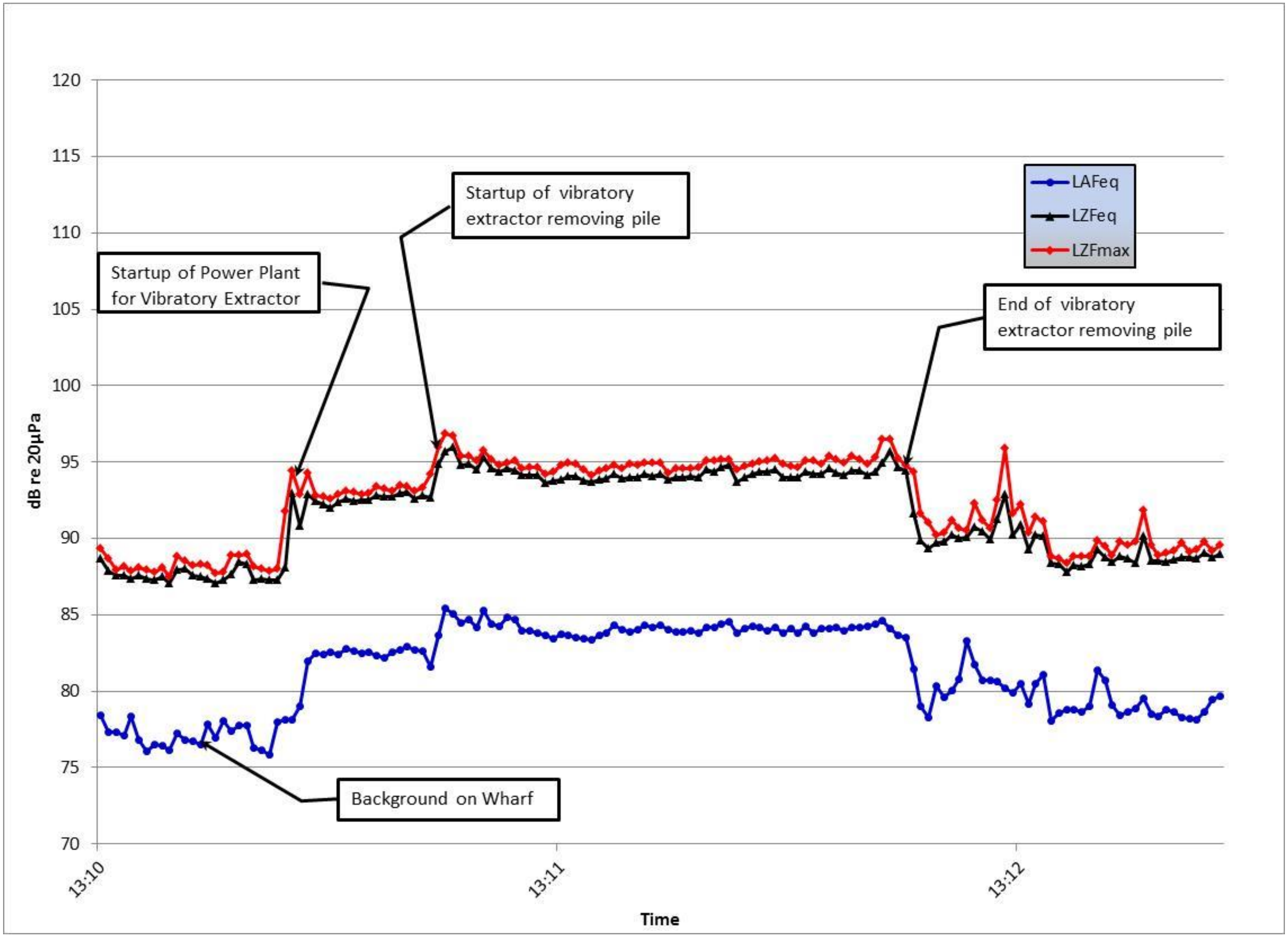

Figure C-10. Airborne Noise SPLs Recorded During Removal of ELCS Pile #8 at JEB Little Creek, 10 September 2015.

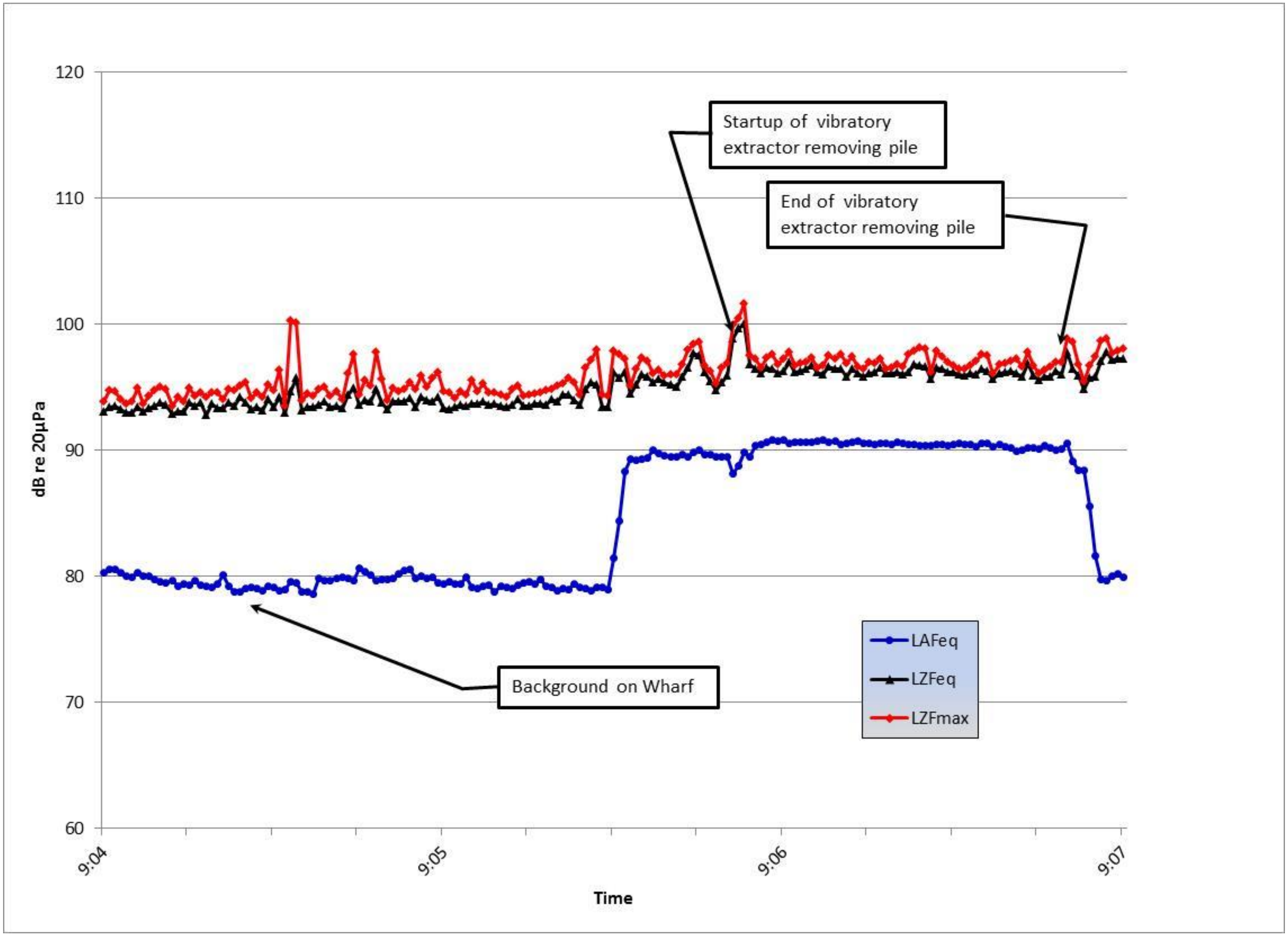

Figure C-11. Airborne Noise SPLs Recorded During Removal of ELCS Pile #1-A at JEB Little Creek, 11 September 2015.

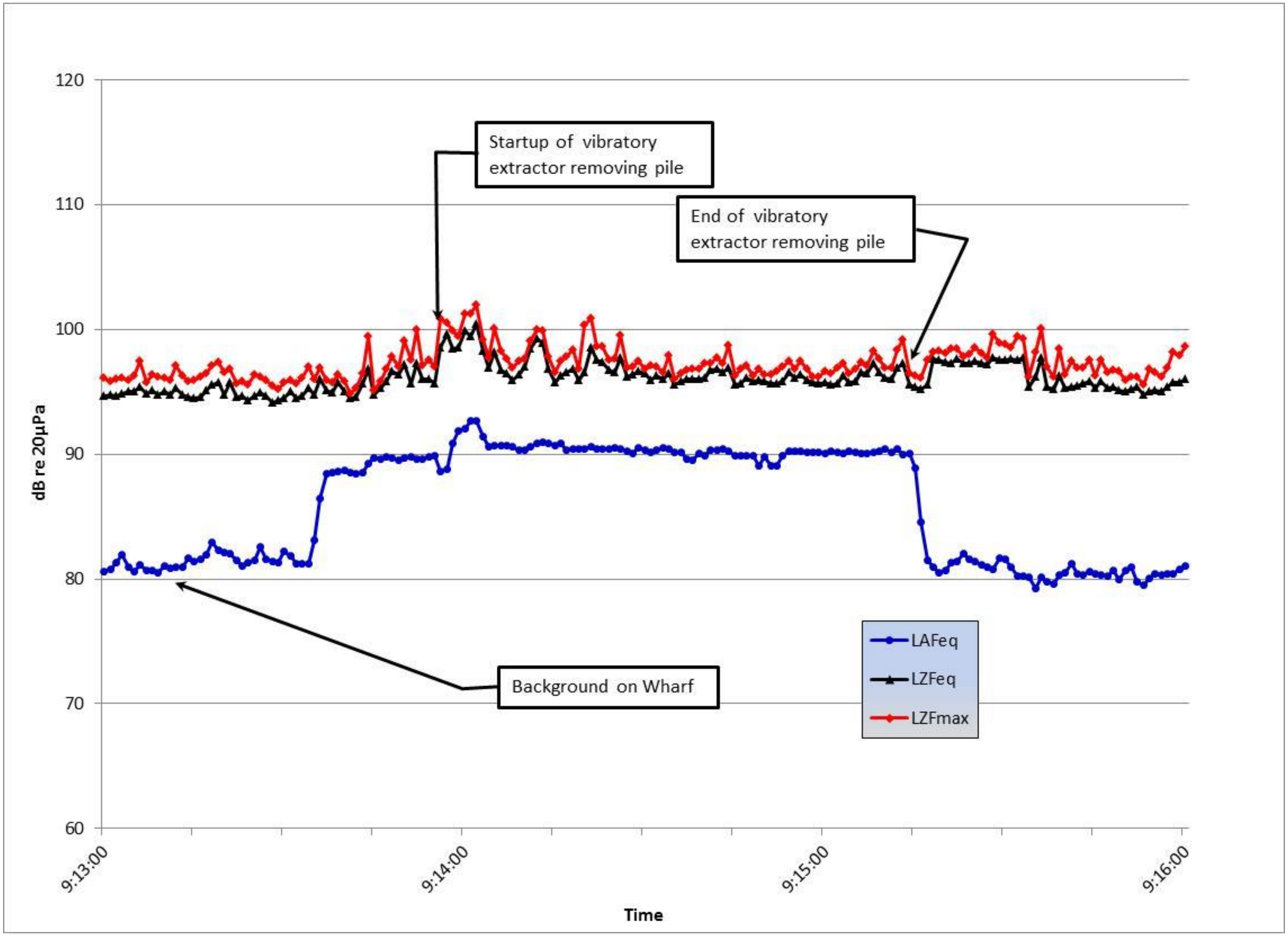

Figure C-12. Airborne Noise SPLs Recorded During Removal of ELCS Pile #2-A at JEB Little Creek, 11 September 2015.

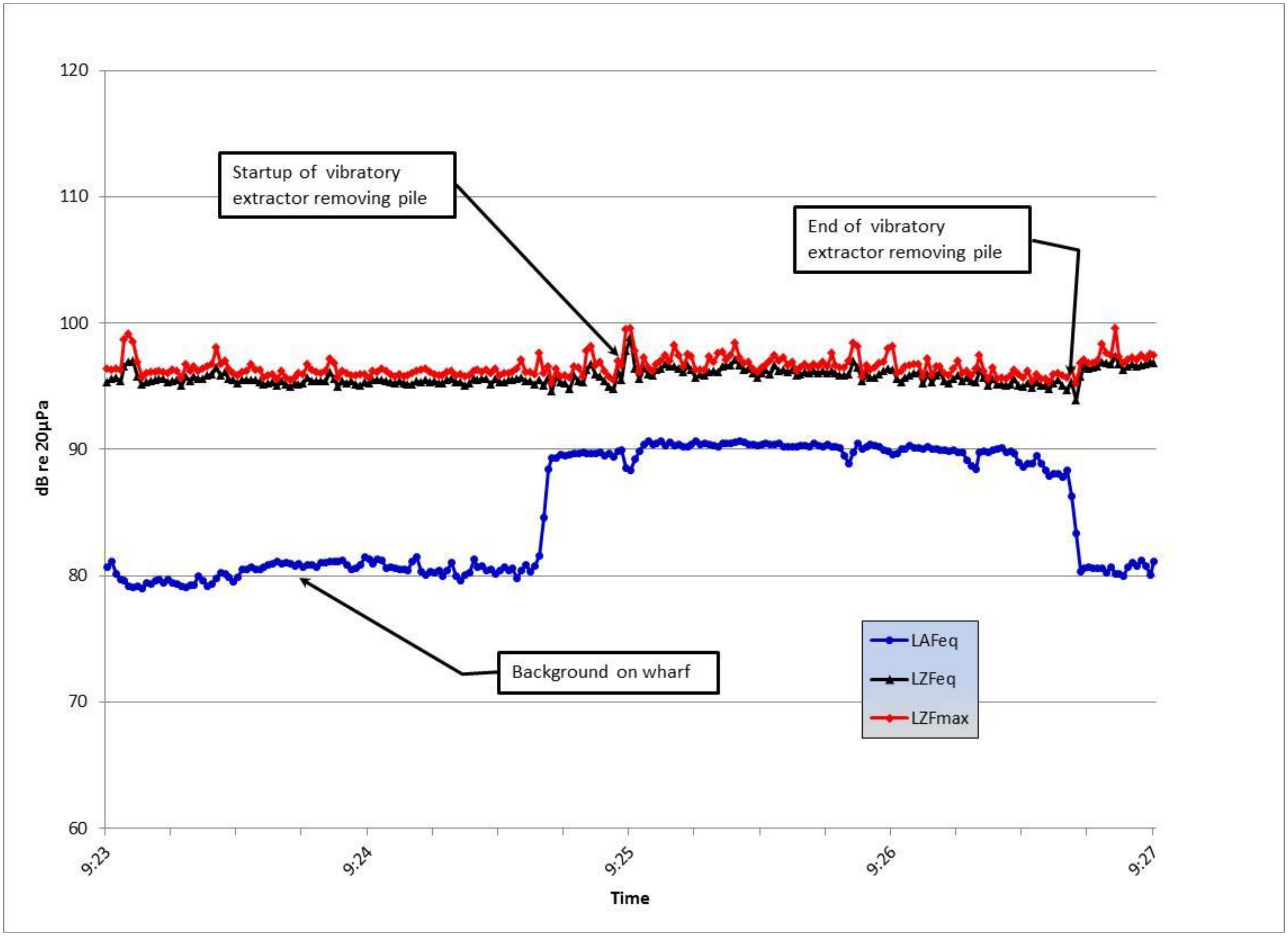

Figure C-13. Airborne Noise SPLs Recorded During Removal of ELCS Pile #3-A at JEB Little Creek, 11 September 2015.

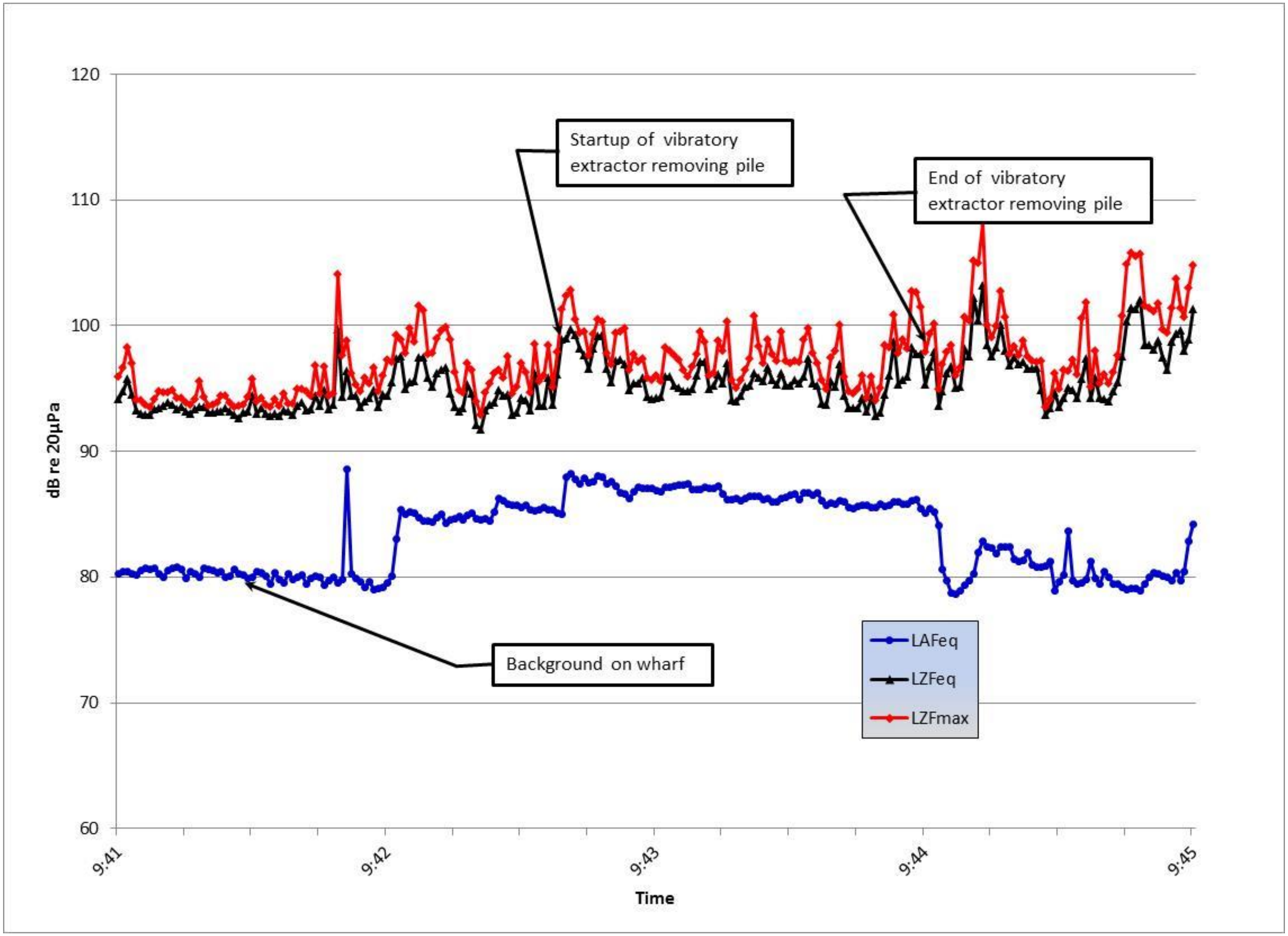

Figure C-14. Airborne Noise SPLs Recorded During Removal of ELCS Pile #4A at JEB Little Creek, 11 September 2015.

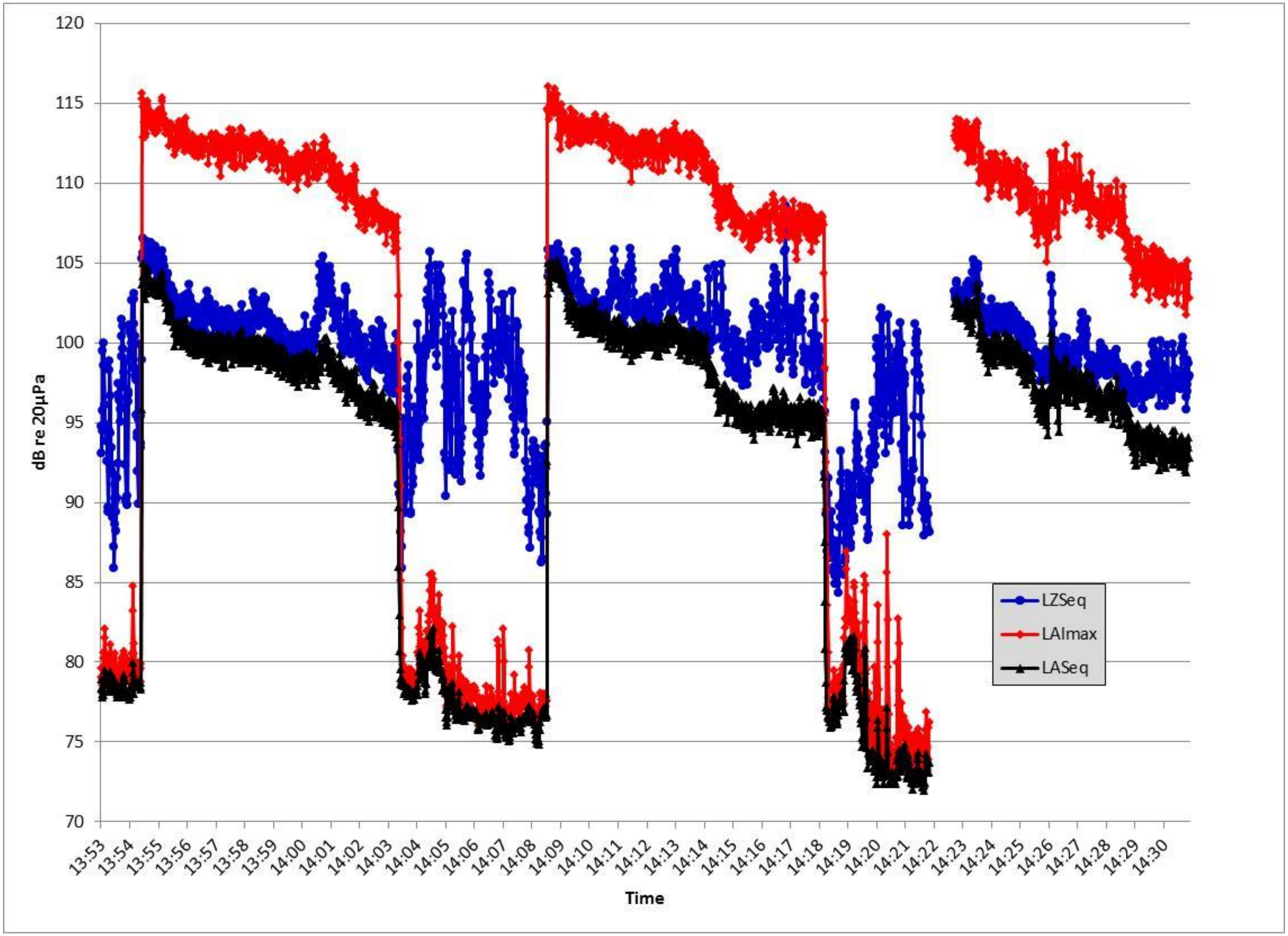

Figure C-15. Airborne Noise SPLs Recorded During Installation of ELCAS Piles at JEB Little Creek, 26 April 2016

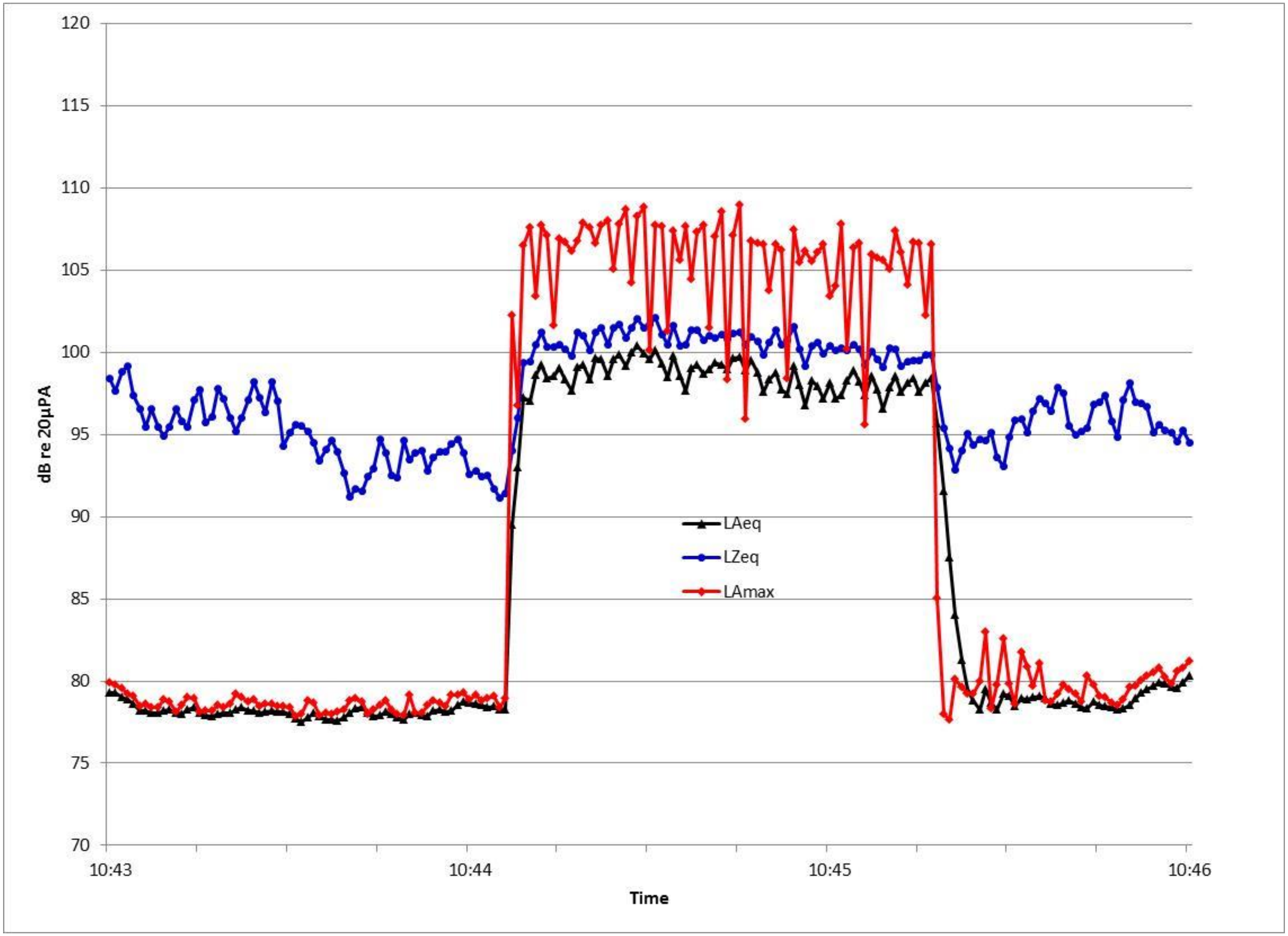

Figure C-16. Airborne Noise SPLs Recorded During Installation of ELCAS Piles at JEB Little Creek, 27 April 2016

Table C-1. One Minute A-Weighted Airborne Data for Craney Island and JEB Little Creek, 28-30 May 2013

Date	Time (EDT)	L_{eq} (dB re 20 μPa)	L_{max} (dB re 20 μPa)	Description of work
Measurements made at 15 meters				
28-May-13	10:23:00	62.4	73.1	No Pile Driving
28-May-13	10:24:00	90	99.9	Installing Sheet Pile
28-May-13	10:25:00	94.8	99.7	
28-May-13	10:26:00	81.8	90.9	
28-May-13	10:27:00	84.7	88.9	
28-May-13	10:28:00	75.8	84.2	
28-May-13	10:29:00	62.2	73.9	No Pile Driving
28-May-13	10:30:00	64.1	79.1	
28-May-13	10:31:00	63	75.4	
28-May-13	10:32:00	61.9	75.1	
28-May-13	10:33:00	61.1	69.4	
28-May-13	10:34:00	61.8	70.7	
28-May-13	10:35:00	63.5	74.7	
28-May-13	10:36:00	61.5	69.8	
28-May-13	10:37:00	61.9	72.2	
28-May-13	10:38:00	61.5	70.2	
28-May-13	10:39:00	61.1	68.9	
28-May-13	10:40:00	61.2	72.4	
28-May-13	10:41:00	62	72	
28-May-13	10:42:00	60.5	74.8	
28-May-13	10:43:00	61.7	73.4	
28-May-13	10:44:00	62	73.2	
28-May-13	10:45:00	71.9	94.4	
28-May-13	10:46:00	62.9	75.7	
28-May-13	10:47:00	63.5	75.3	
28-May-13	10:48:00	63.4	75	
28-May-13	10:49:00	62	68.3	
28-May-13	10:50:00	62	67.1	
28-May-13	10:51:00	63	70.4	
28-May-13	10:52:00	61.9	66.3	
28-May-13	10:53:00	84	91.4	Installing Sheet Pile
28-May-13	10:54:00	79.1	87.2	
28-May-13	10:55:00	83.5	88.8	
28-May-13	10:56:00	81.5	83	
28-May-13	10:57:00	60.3	70.4	
28-May-13	10:58:00	58.2	61.8	No Pile Driving
28-May-13	10:59:00	57.2	62.6	
28-May-13	11:00:00	58.8	64	
28-May-13	13:31:00	58.7	64.5	
28-May-13	13:32:00	60.3	66.3	
28-May-13	13:33:00	60.9	68.8	
28-May-13	13:34:00	58.9	63.4	

Date	Time (EDT)	L_{eq} (dB re 20 µPa)	L_{max} (dB re 20 µPa)	Description of work
28-May-13	13:35:00	72.4	77.6	
28-May-13	13:36:00	77	82.4	
28-May-13	13:37:00	64.6	75.9	
28-May-13	13:38:00	62.9	68.6	
28-May-13	13:39:00	63.8	71	
28-May-13	13:40:00	75.9	80.5	
28-May-13	13:41:00	67	77.8	
28-May-13	13:42:00	59.2	61.9	
28-May-13	13:43:00	60.8	65	
28-May-13	13:44:00	70.5	80	
28-May-13	13:45:00	79.2	84.7	
28-May-13	13:46:00	64.7	69.5	
28-May-13	13:47:00	77.9	83	
28-May-13	13:48:00	76.6	80.1	
28-May-13	13:49:00	60.8	69.4	
28-May-13	13:50:00	62.5	72.7	
28-May-13	13:51:00	61.9	75.4	
28-May-13	13:52:00	69.2	80.9	Removing H-Pile
28-May-13	13:53:00	80.5	82.4	
28-May-13	13:54:00	79.6	83.2	
28-May-13	13:55:00	64	70.7	No Pile Driving
28-May-13	13:56:00	65.1	71.4	
28-May-13	13:57:00	66.7	70.2	
28-May-13	13:58:00	59.5	65.9	
28-May-13	13:59:00	61.2	66	
28-May-13	14:00:00	72.5	83.2	Installing H-Pile
28-May-13	14:01:00	76.3	81.7	
28-May-13	14:02:00	77.7	84.3	
28-May-13	14:03:00	79	84.4	
28-May-13	14:04:00	62.8	74.7	
28-May-13	14:05:00	70.6	83.5	
28-May-13	14:06:00	77	84.7	
28-May-13	14:07:00	78.9	83.3	
28-May-13	14:08:00	78.2	81	
28-May-13	14:09:00	76.7	81.9	
28-May-13	14:10:00	73.3	81.4	
28-May-13	14:11:00	64.9	71.9	No Pile Driving
28-May-13	14:12:00	62.1	66.2	
28-May-13	14:13:00	60.2	68.1	
28-May-13	14:14:00	58.3	65.3	
28-May-13	14:15:00	57.9	67.4	
28-May-13	14:16:00	55.1	65.4	
28-May-13	14:17:00	58.3	65.9	
28-May-13	14:18:00	57	65.4	
28-May-13	14:19:00	57.9	75.6	

Date	Time (EDT)	L_{eq} (dB re 20 µPa)	L_{max} (dB re 20 µPa)	Description of work
Measurements made at 15 meters				
29-May-13	13:40:00	82.4	88.8	No Pile Driving
29-May-13	13:41:00	57.2	68.7	
29-May-13	13:42:00	84.2	97.8	
29-May-13	13:43:00	91.7	97.2	
29-May-13	13:44:00	90.3	92.6	
29-May-13	13:45:00	90.8	93.2	
29-May-13	13:46:00	91.1	94.8	
29-May-13	13:47:00	87.7	93.4	
29-May-13	13:48:00	85.9	89.9	
29-May-13	13:49:00	59	71.7	
29-May-13	13:50:00	71.3	82.4	
29-May-13	13:51:00	87.1	94.3	
29-May-13	13:52:00	58.6	68.4	
29-May-13	13:53:00	92.3	102.3	
29-May-13	13:54:00	87.6	97.8	
29-May-13	13:55:00	84.2	92.2	Impact Driving
29-May-13	13:56:00	59.6	70.2	No Pile Driving
29-May-13	13:57:00	80.2	90.2	
29-May-13	13:58:00	88.3	99.3	
29-May-13	13:59:00	57.9	63.2	
29-May-13	14:00:00	58.5	70.7	
29-May-13	14:01:00	60.5	68.6	
29-May-13	14:02:00	69	91.4	Impact Driving
29-May-13	14:03:00	66.4	82.7	No Pile Driving
29-May-13	14:04:00	74.2	86.7	
29-May-13	14:05:00	68.4	83.1	
29-May-13	14:06:00	72.4	93.6	
29-May-13	14:07:00	68.3	82.8	
29-May-13	14:08:00	59.7	76.3	
29-May-13	14:09:00	62.4	73.8	
29-May-13	14:10:00	62.1	77.7	
Measurements made at 27-30 meters				
30-May-13	7:30:00	61	63.4	No Pile Driving
30-May-13	7:31:00	63.1	68.4	
30-May-13	7:32:00	63.4	66.9	
30-May-13	7:33:00	78.2	93.8	
30-May-13	7:34:00	63.9	70	
30-May-13	7:35:00	82.7	100.4	Installing Sheet Pile
30-May-13	7:36:00	94.6	98.5	
30-May-13	7:37:00	87.2	94.3	
30-May-13	7:38:00	63.6	69	No Pile Driving
30-May-13	7:39:00	64.2	73.9	
30-May-13	7:40:00	80	85.8	Installing Sheet Pile

Date	Time (EDT)	L_{eq} (dB re 20 μPa)	L_{max} (dB re 20 μPa)	Description of work
Measurements made at 27-30 meters (continued)				
30-May-13	7:41:00	64.3	68.3	No Pile Driving
30-May-13	7:42:00	64.3	69.7	
30-May-13	7:43:00	91.1	95.3	Installing Sheet Pile
30-May-13	7:44:00	84.1	90.9	
30-May-13	7:45:00	84	87.9	
30-May-13	7:46:00	63.8	73.6	No Pile Driving
30-May-13	7:47:00	63.8	69.2	
30-May-13	7:48:00	64.1	67.4	
30-May-13	7:49:00	82.2	94.7	Installing Sheet Pile Two Sheet Piles
30-May-13	7:50:00	81.1	92.3	
30-May-13	7:51:00	89.7	95.9	
30-May-13	7:52:00	81.7	87.6	
30-May-13	7:53:00	69.3	84.5	No Pile Driving
30-May-13	10:57:00	78	80.2	Install H-Pile
30-May-13	10:58:00	72.8	79.2	
30-May-13	10:59:00	61.7	66	No Pile Driving
30-May-13	11:00:00	77.7	82.4	Removing H-Pile
30-May-13	11:01:00	68.2	79.4	
30-May-13	11:02:00	63.8	74.2	No Pile Driving
30-May-13	11:03:00	64.6	72.5	
30-May-13	11:04:00	63.4	76.5	
30-May-13	11:05:00	76.6	79.9	Install H-Pile
30-May-13	11:06:00	75.9	78.3	
30-May-13	11:07:00	71.4	77.9	
30-May-13	11:08:00	60.2	66.7	No Pile Driving
30-May-13	11:09:00	58.6	66.1	
30-May-13	11:10:00	60.1	70.4	
30-May-13	11:11:00	58.2	61.8	
30-May-13	11:12:00	67.2	78.4	
30-May-13	11:13:00	80.5	83	Removing H-Pile
30-May-13	11:14:00	81.2	83.5	
30-May-13	11:15:00	71.3	82.3	
30-May-13	11:16:00	70	84.8	
30-May-13	11:17:00	58.9	61.8	No Pile Driving
30-May-13	11:18:00	58.3	62.6	
30-May-13	11:19:00	75.8	79.7	Install H-Pile
30-May-13	11:20:00	65.3	77.8	
30-May-13	11:21:00	57.4	59.9	No Pile Driving
30-May-13	11:22:00	58.3	63.1	
30-May-13	11:23:00	57.9	63.3	
30-May-13	15:10:00	63.4	66.7	
30-May-13	15:11:00	62.1	63.8	
30-May-13	15:12:00	62	64.5	
30-May-13	15:13:00	61.6	64.1	

Date	Time (EDT)	L_{eq} (dB re 20 µPa)	L_{max} (dB re 20 µPa)	Description of work
Measurements made at 27-30 meters (continued)				
30-May-13	15:14:00	64	74.3	Installing H-Pile
30-May-13	15:15:00	68.6	71.9	
30-May-13	15:16:00	69.2	70.6	
30-May-13	15:17:00	69.7	71	
30-May-13	15:18:00	70.6	74.4	
30-May-13	15:19:00	68.7	73.7	
30-May-13	15:20:00	71.2	79.6	
30-May-13	15:21:00	68.4	75.2	
30-May-13	15:22:00	61.8	64.1	No Pile Driving
30-May-13	15:23:00	60.9	65.5	
30-May-13	15:24:00	69.2	73.9	Installing H-Pile
30-May-13	15:25:00	73.5	75.3	
30-May-13	15:26:00	67.3	79.9	
30-May-13	15:27:00	63.9	74.8	No Pile Driving
30-May-13	15:28:00	62	65.4	
30-May-13	15:29:00	62.5	69.5	
30-May-13	15:30:00	71.5	75.7	Removing H-Pile
30-May-13	15:31:00	69.6	75.9	
30-May-13	15:32:00	63.8	68.1	No Pile Driving
30-May-13	15:33:00	61.6	63.6	
30-May-13	15:34:00	69.1	74	Installing H-Pile
30-May-13	15:35:00	72.8	74	
30-May-13	15:36:00	73.2	74.6	
30-May-13	15:37:00	73.3	74.5	
30-May-13	15:38:00	67.6	78.7	
30-May-13	15:39:00	64.5	71.5	No Pile Driving
30-May-13	15:40:00	62.3	65.2	
30-May-13	15:41:00	64.4	71.6	
30-May-13	15:42:00	66	71.7	
30-May-13	15:43:00	69	81.9	
30-May-13	15:44:00	62.6	70.7	

Table C-2. One Minute A-Weighted Airborne Data, Philadelphia Naval Shipyard, 01 October 2014

Date	Time (EDT)	LAeq (dB re 20 µPa)	LAmax (dB re 20 µPa)	Description of work
1-Oct-14	13:26:08	79	83	No Driving
1-Oct-14	13:27:00	77	79	
1-Oct-14	13:28:00	77	80	
1-Oct-14	13:29:00	79	84	
1-Oct-14	13:30:00	77	83	
1-Oct-14	13:31:00	78	81	
1-Oct-14	13:32:00	77	83	
1-Oct-14	13:33:00	78	86	
1-Oct-14	13:34:00	79	81	
1-Oct-14	13:35:00	79	83	
1-Oct-14	13:36:00	79	84	
1-Oct-14	13:37:00	78	80	
1-Oct-14	13:38:00	80	89	
1-Oct-14	13:39:00	86	95	
1-Oct-14	13:40:00	81	90	
Impact Driving				
1-Oct-14	13:41:00	102	113	Pile D4
1-Oct-14	13:42:00	105	112	
1-Oct-14	13:43:00	105	113	
1-Oct-14	13:44:00	105	113	
1-Oct-14	13:45:00	105	113	
1-Oct-14	13:46:00	105	113	
1-Oct-14	13:47:00	105	113	
1-Oct-14	13:48:00	105	113	
1-Oct-14	13:49:00	105	112	
1-Oct-14	13:50:00	104	112	
1-Oct-14	13:51:00	105	113	
1-Oct-14	13:52:00	104	113	
1-Oct-14	13:53:00	78	83	No Driving
1-Oct-14	13:54:00	79	83	
1-Oct-14	13:55:00	80	92	
1-Oct-14	13:56:00	79	81	
1-Oct-14	13:57:00	79	85	
1-Oct-14	13:58:00	78	81	
1-Oct-14	13:59:00	78	83	
1-Oct-14	14:00:00	87	104	
1-Oct-14	14:01:00	89	106	
1-Oct-14	14:02:00	90	106	
1-Oct-14	14:03:00	89	105	
1-Oct-14	14:04:00	79	89	
1-Oct-14	14:05:00	79	90	
1-Oct-14	14:06:00	80	89	
1-Oct-14	14:07:00	83	92	
1-Oct-14	14:08:00	79	87	
1-Oct-14	14:09:00	77	86	
1-Oct-14	14:10:00	75	82	
1-Oct-14	14:11:00	75	79	

Date	Time (EDT)	LAeq (dB re 20 µPa)	LAmax (dB re 20 µPa)	Description of work
Impact Driving (continued)				
1-Oct-14	14:12:00	76	84	
1-Oct-14	14:13:00	75	90	
1-Oct-14	14:14:00	98	107	
1-Oct-14	14:15:00	103	111	Pile D4 (Continued)
1-Oct-14	14:16:00	104	112	
1-Oct-14	14:17:00	105	112	
1-Oct-14	14:18:00	105	112	
1-Oct-14	14:19:00	105	113	
1-Oct-14	14:20:00	105	113	
1-Oct-14	14:21:00	105	112	
1-Oct-14	14:22:00	92	106	No Driving
1-Oct-14	14:23:00	81	88	
1-Oct-14	14:24:00	79	86	
1-Oct-14	14:25:00	82	90	
1-Oct-14	14:26:00	107	115	Pile E4
1-Oct-14	14:27:00	108	116	
1-Oct-14	14:28:00	108	116	
1-Oct-14	14:29:00	108	116	
1-Oct-14	14:30:00	108	116	
1-Oct-14	14:31:00	108	116	
1-Oct-14	14:32:00	107	116	
1-Oct-14	14:33:00	107	116	
1-Oct-14	14:34:00	81	86	No Driving
1-Oct-14	14:35:00	82	90	
1-Oct-14	14:36:00	79	82	
1-Oct-14	14:37:00	79	85	
1-Oct-14	14:38:00	79	93	
1-Oct-14	14:39:00	83	91	
1-Oct-14	14:40:00	81	89	
1-Oct-14	14:41:00	83	94	
1-Oct-14	14:42:00	81	91	
1-Oct-14	14:43:00	79	82	
1-Oct-14	14:44:00	79	97	
1-Oct-14	14:45:00	78	89	
1-Oct-14	14:46:00	106	117	Pile E4 (Continued)
1-Oct-14	14:47:00	109	117	
1-Oct-14	14:48:00	109	116	
1-Oct-14	14:49:00	108	116	
1-Oct-14	14:50:00	107	115	
1-Oct-14	14:51:00	79	88	No Driving
1-Oct-14	14:52:00	80	90	
1-Oct-14	14:53:00	79	85	
1-Oct-14	14:54:00	104	112	Pile F4
1-Oct-14	14:55:00	105	113	
1-Oct-14	14:56:00	106	114	

Date	Time (EDT)	LAeq (dB re 20 µPa)	LAmax (dB re 20 µPa)	Description of work
Impact Driving (continued)				
1-Oct-14	14:57:00	106	113	
1-Oct-14	14:58:00	106	113	
1-Oct-14	14:59:00	106	114	
1-Oct-14	15:00:00	105	113	
1-Oct-14	15:01:00	105	114	
1-Oct-14	15:02:00	101	114	
1-Oct-14	15:03:00	83	94	No Driving
1-Oct-14	15:04:00	82	92	
1-Oct-14	15:05:00	85	94	
1-Oct-14	15:06:00	82	92	
1-Oct-14	15:07:00	85	93	
1-Oct-14	15:08:00	79	83	
1-Oct-14	15:09:00	80	92	
1-Oct-14	15:10:00	79	84	
1-Oct-14	15:11:00	100	111	Pile F4 (Continued)
1-Oct-14	15:12:00	104	112	
1-Oct-14	15:13:00	104	112	
1-Oct-14	15:14:00	104	112	
1-Oct-14	15:15:00	105	112	
1-Oct-14	15:16:00	105	113	
1-Oct-14	15:17:00	105	113	
1-Oct-14	15:18:00	99	112	No Driving
1-Oct-14	15:19:00	81	91	
1-Oct-14	15:20:00	81	91	
1-Oct-14	15:21:00	85	95	
1-Oct-14	15:22:00	97	108	
1-Oct-14	15:23:00	102	109	Pile G4
1-Oct-14	15:24:00	103	110	
1-Oct-14	15:25:00	102	109	
1-Oct-14	15:26:00	102	108	
1-Oct-14	15:27:00	101	108	
1-Oct-14	15:28:00	101	108	
1-Oct-14	15:29:00	101	108	
1-Oct-14	15:30:00	100	107	
1-Oct-14	15:31:00	100	107	
1-Oct-14	15:32:00	101	107	
1-Oct-14	15:33:00	100	107	
1-Oct-14	15:34:00	100	106	
1-Oct-14	15:35:00	100	107	
1-Oct-14	15:36:00	100	107	
1-Oct-14	15:37:00	95	106	No Driving
1-Oct-14	15:38:00	90	99	
1-Oct-14	15:39:00	73	83	
1-Oct-14	15:40:00	74	85	
1-Oct-14	15:41:00	69	73	

Table C-3. One Minute A-Weighted Airborne, Data Philadelphia Naval Shipyard, 02 October 2014

Date	Time (EDT)	L_{eq} (dB re 20 µPa)	L_{max} (dB re 20 µPa)	Pile ID
Vibratory Driving				
2-Oct-14	08:50:00	99	108	Pile D3
2-Oct-14	08:51:00	99	103	
2-Oct-14	08:52:00	96	104	
2-Oct-14	08:53:00	98	101	
2-Oct-14	08:54:00	95	102	
2-Oct-14	08:55:00	95	101	
2-Oct-14	08:56:00	87	91	No Driving
2-Oct-14	08:57:00	83	86	
2-Oct-14	08:58:00	83	86	
2-Oct-14	08:59:00	97	103	Pile E3
2-Oct-14	09:00:00	100	103	
2-Oct-14	09:01:00	93	102	
2-Oct-14	09:02:00	98	103	
2-Oct-14	09:03:00	93	101	
2-Oct-14	09:04:00	95	100	
2-Oct-14	09:05:00	87	99	
2-Oct-14	09:06:00	78	79	No Driving
2-Oct-14	09:07:00	79	86	
2-Oct-14	09:08:00	89	96	Pile G3
2-Oct-14	09:09:00	86	95	
2-Oct-14	09:10:00	82	91	
2-Oct-14	09:11:00	78	79	
2-Oct-14	09:12:00	91	94	
2-Oct-14	09:13:00	91	94	
2-Oct-14	09:14:00	88	94	
2-Oct-14	09:15:00	92	95	
2-Oct-14	09:16:00	92	94	
2-Oct-14	09:17:00	91	96	
2-Oct-14	09:18:00	79	81	No Driving
2-Oct-14	09:19:00	78	81	
2-Oct-14	09:20:00	78	82	
2-Oct-14	09:21:00	80	92	
2-Oct-14	09:22:00	82	86	
2-Oct-14	09:23:00	90	98	Pile H4
2-Oct-14	09:24:00	93	96	
2-Oct-14	09:25:00	85	96	
2-Oct-14	09:26:00	81	83	No Driving
2-Oct-14	09:27:00	80	81	
2-Oct-14	09:28:00	80	83	

Date	Time (EDT)	L_{eq} (dB re 20 µPa)	L_{max} (dB re 20 µPa)	Pile ID
Vibratory Driving (continued)				
2-Oct-14	09:29:00	83	96	Pile I4
2-Oct-14	09:30:00	93	99	
2-Oct-14	09:31:00	98	102	
2-Oct-14	09:32:00	94	98	
2-Oct-14	09:33:00	94	99	
2-Oct-14	09:34:00	92	97	
2-Oct-14	09:35:00	90	96	
Impact Driving				
2-Oct-14	11:34:00	104	111	Pile G3
2-Oct-14	11:35:00	104	111	
2-Oct-14	11:36:00	104	112	
2-Oct-14	11:37:00	104	112	
2-Oct-14	11:38:00	104	112	
2-Oct-14	11:39:00	103	112	
2-Oct-14	11:40:00	103	111	
2-Oct-14	11:41:00	103	111	
2-Oct-14	11:42:00	102	111	
2-Oct-14	11:43:00	102	110	
2-Oct-14	11:44:00	103	111	
2-Oct-14	11:45:00	102	110	
2-Oct-14	11:46:00	103	112	
2-Oct-14	11:47:00	103	111	
2-Oct-14	11:48:00	103	111	
2-Oct-14	11:49:00	102	111	
2-Oct-14	11:50:00	92	110	No Driving
2-Oct-14	11:51:00	79	86	
2-Oct-14	11:52:00	79	88	
2-Oct-14	11:53:00	78	93	
2-Oct-14	11:54:00	78	88	
2-Oct-14	11:55:00	75	86	
2-Oct-14	11:56:00	102	110	Pile H4
2-Oct-14	11:57:00	103	111	
2-Oct-14	11:58:00	104	111	
2-Oct-14	11:59:00	104	111	
2-Oct-14	12:00:00	103	111	
2-Oct-14	12:01:00	103	110	
2-Oct-14	12:02:00	103	111	
2-Oct-14	12:03:00	98	112	

Date	Time (EDT)	L_{eq} (dB re 20 µPa)	L_{max} (dB re 20 µPa)	Pile ID
Impact Driving (continued)				
2-Oct-14	12:04:00	77	86	Pause No Driving
2-Oct-14	12:05:00	80	91	
2-Oct-14	12:06:00	77	87	
2-Oct-14	12:07:00	81	90	
2-Oct-14	12:08:00	80	90	
2-Oct-14	12:09:00	72	81	
2-Oct-14	12:10:00	76	89	
2-Oct-14	12:11:00	74	86	
2-Oct-14	12:12:00	72	86	
2-Oct-14	12:13:00	78	91	
2-Oct-14	12:14:00	83	91	
2-Oct-14	12:15:00	74	88	
2-Oct-14	12:16:00	81	90	
2-Oct-14	12:17:00	80	88	
2-Oct-14	12:18:00	73	84	
2-Oct-14	12:19:00	73	85	
2-Oct-14	12:20:00	74	88	
2-Oct-14	12:21:00	103	112	Pile H4 (cont.)
2-Oct-14	12:22:00	105	112	
2-Oct-14	12:23:00	105	112	
2-Oct-14	12:24:00	104	111	
2-Oct-14	12:25:00	103	111	
2-Oct-14	12:26:00	104	111	
2-Oct-14	12:27:00	98	110	
2-Oct-14	12:28:00	75	86	No Driving
2-Oct-14	12:29:00	77	88	
2-Oct-14	12:30:00	78	89	
2-Oct-14	12:31:00	80	84	
2-Oct-14	12:32:00	97	111	Pile I4
2-Oct-14	12:33:00	102	109	
2-Oct-14	12:34:00	102	110	
2-Oct-14	12:35:00	102	110	
2-Oct-14	12:36:00	103	110	
2-Oct-14	12:37:00	103	111	
2-Oct-14	12:38:00	103	110	
2-Oct-14	12:39:00	103	111	
2-Oct-14	12:40:00	98	110	

Date	Time (EDT)	L_{eq} (dB re 20 µPa)	L_{max} (dB re 20 µPa)	Pile ID
Impact Driving (continued)				
2-Oct-14	12:41:00	80	85	Pause No Driving
2-Oct-14	12:42:00	81	91	
2-Oct-14	12:43:00	81	93	
2-Oct-14	12:44:00	79	84	
2-Oct-14	12:45:00	79	82	
2-Oct-14	12:46:00	79	83	
2-Oct-14	12:47:00	82	89	
2-Oct-14	12:48:00	84	93	
2-Oct-14	12:49:00	82	91	
2-Oct-14	12:50:00	84	92	
2-Oct-14	12:51:00	80	87	
2-Oct-14	12:52:00	79	87	
2-Oct-14	12:53:00	79	85	
2-Oct-14	12:54:00	104	112	Pile I4 (cont.)
2-Oct-14	12:55:00	105	112	
2-Oct-14	12:56:00	105	113	
2-Oct-14	12:57:00	104	112	
2-Oct-14	12:58:00	104	112	
2-Oct-14	12:59:00	103	111	
2-Oct-14	13:00:00	103	111	
2-Oct-14	13:01:00	103	111	
2-Oct-14	13:02:00	99	111	

Table C-4. One Minute A-Weighted Airborne Data, Naval Station Norfolk Yard, 21-25 October 2014

Date	Time (EDT)	L_{eq} (dB re 20 µPa)	L_{max} (dB re 20 µPa)	Notes
Impact Driving Concrete Fender Piles				
21-Oct-14	14:12:00	79.6	82.3	No Pile Driving
21-Oct-14	14:15:00	80.6	88.6	
21-Oct-14	14:16:00	79.9	84.8	
21-Oct-14	14:17:00	96.5	101.6	
21-Oct-14	14:18:00	92.6	100.1	
21-Oct-14	14:19:00	84.8	99.5	No Pile Driving
21-Oct-14	14:20:00	93.8	102.5	
21-Oct-14	14:21:00	87.3	98.4	No Pile Driving
21-Oct-14	14:22:00	83.3	97.7	
21-Oct-14	14:23:00	75.8	76.5	
21-Oct-14	14:24:00	94.6	100	
21-Oct-14	14:25:00	89.1	101.4	
21-Oct-14	14:26:00	83.8	100.2	
21-Oct-14	14:27:00	82.2	97.7	No Pile Driving
21-Oct-14	14:28:00	81.3	88.7	
21-Oct-14	14:29:00	77.6	82.5	
25-Oct-14	11:21:00	66.7	71.7	No Pile Driving
25-Oct-14	11:22:00	70.2	83.6	
25-Oct-14	11:23:00	83.9	100.2	
25-Oct-14	11:24:00	96.7	101.7	
25-Oct-14	11:25:00	68.7	80.8	No Pile Driving
25-Oct-14	11:26:00	86.8	100.2	
25-Oct-14	11:27:00	96.2	100.5	
25-Oct-14	11:28:00	67.2	74	No Pile Driving
25-Oct-14	11:29:00	97.3	102.4	
25-Oct-14	11:30:00	87.6	100.3	
25-Oct-14	11:31:00	95.5	101.7	
25-Oct-14	11:32:00	98.3	101.7	
25-Oct-14	11:33:00	69.4	75.2	No Pile Driving
25-Oct-14	11:34:00	98.2	102.5	
25-Oct-14	11:35:00	93.6	100.7	
25-Oct-14	11:36:00	98	100.8	
25-Oct-14	11:37:00	69.5	75.3	No Pile Driving
25-Oct-14	11:38:00	87.7	99.8	
25-Oct-14	11:39:00	73	87.6	
25-Oct-14	11:40:00	86.4	99.6	
25-Oct-14	11:41:00	69.5	73.7	

Table C-5*.* One Minute A-Weighted Airborne Data, Naval Station Norfolk, 27 October 2014

Date	Time (EDT)	L_{eq} (dB re 20 µPa)	L_{max} (dB re 20 µPa)	Notes
Vibratory Driving				
10/27/2014	12:43:00	65.8	76	No Pile Driving
10/27/2014	12:44:00	78.5	83.5	
10/27/2014	12:45:00	79.4	83.7	
10/27/2014	12:46:00	81.6	85.6	Pile #1
10/27/2014	12:47:00	82.3	84.5	
10/27/2014	12:48:00	75.1	84.1	No Pile Driving
10/27/2014	12:49:00	80.8	85.5	Pile #2
10/27/2014	12:50:00	84.9	85.9	
10/27/2014	12:51:00	80.4	84.2	
10/27/2014	12:52:00	79.7	83.6	No Pile Driving
10/27/2014	12:53:00	81.4	86.2	Pile #3
10/27/2014	12:54:00	77.8	85.6	
10/27/2014	12:55:00	77.9	82.4	No Pile Driving
10/27/2014	12:56:00	79.6	83.4	
10/27/2014	12:57:00	83.8	87.6	Pile #4
10/27/2014	12:58:00	77.7	84.6	No Pile Driving
10/27/2014	12:59:00	79.9	83.2	
10/27/2014	13:00:00	83.3	87.1	Pile #5
10/27/2014	13:01:00	78.5	83.4	No Pile Driving
10/27/2014	13:02:00	81.2	86.4	Pile #6
10/27/2014	13:03:00	78.4	86.3	
10/27/2014	13:04:00	75.2	82.9	No Pile Driving
10/27/2014	13:05:00	76.9	83.5	
10/27/2014	13:06:00	77.9	83	
10/27/2014	13:07:00	83.6	86.5	Pile #7
10/27/2014	13:08:00	78.4	83.4	No Pile Driving
10/27/2014	13:09:00	80.7	83.3	
10/27/2014	13:10:00	74.9	83.4	
10/27/2014	13:11:00	83.7	87.7	Pile #8
10/27/2014	13:12:00	79.3	85.8	
10/27/2014	13:13:00	80.1	83.6	No Pile Driving
10/27/2014	13:14:00	83.6	86.3	Pile #9
10/27/2014	13:15:00	75.1	84.3	No Pile Driving
10/27/2014	13:16:00	77.5	82.8	
10/27/2014	13:17:00	65.3	69.3	
10/27/2014	13:18:00	65.5	74.8	
10/27/2014	13:19:00	65.5	70.1	

Table C-6. One Minute A-Weighted Airborne Data for King Piles, Naval Station Mayport, 09 June 2015

Date	Time (EDT)	LA_{eq} (dB re 20 µPa)	LA_{max} (dB re 20 µPa)	Notes
09-June -15	8:29:09	80.7	85.3	
09-June -15	8:30:09	84.8	91.2	
09-June -15	8:31:09	85.3	87.8	
09-June -15	8:32:09	84.9	87.6	
09-June -15	8:33:09	83.7	86.6	
09-June -15	8:34:09	83.6	86.1	
09-June -15	8:35:09	84.4	87.4	
09-June -15	8:36:09	83.8	86.6	
09-June -15	8:37:09	82.8	87.1	
09-June -15	8:38:09	81.4	85.6	
09-June -15	8:39:09	81.2	84.1	
09-June -15	8:40:09	84.7	86.9	
09-June -15	8:41:09	82.6	84.6	
09-June -15	8:42:09	85.0	87.9	
09-June -15	8:43:09	82.6	84.8	
09-June -15	8:44:09	81.3	82.9	
09-June -15	8:45:09	82.1	86.1	
09-June -15	8:46:09	83.3	86.0	
09-June -15	8:47:09	82.7	84.5	
09-June -15	8:48:09	83.8	86.5	King Pile #1
09-June -15	8:49:09	83.3	86.5	
09-June -15	8:50:09	82.4	84.2	
09-June -15	8:51:09	87.6	84.1	
09-June -15	8:52:09	80.3	81.7	
09-June -15	8:53:09	80.9	84.1	
09-June -15	8:54:09	82.2	83.5	
09-June -15	8:55:09	83.6	86.5	
09-June -15	8:56:09	83.2	84.0	
09-June -15	8:57:09	81.6	84.7	
09-June -15	8:58:09	80.3	82.9	
09-June -15	8:59:09	80.5	82.9	
09-June -15	9:00:09	82.2	84.6	
09-June -15	9:01:09	83.0	84.6	
09-June -15	9:02:09	82.8	83.4	
09-June -15	9:03:09	83.5	84.3	
09-June -15	9:04:09	83.4	84.0	
09-June -15	9:05:09	83.3	84.1	
09-June -15	9:06:09	81.4	82.4	
09-June -15	9:07:09	81.3	83.4	

Date	Time (EDT)	LA_{eq} (dB re 20 µPa)	LA_{max} (dB re 20 µPa)	Notes
09-June -15	9:12:45	85.7	90.7	King Pile #2
09-June -15	9:13:45	83.3	86.9	
09-June -15	9:14:45	81.7	83.6	
09-June -15	9:15:45	84.5	86.7	
09-June -15	9:16:45	85.9	86.6	
09-June -15	9:17:45	84.3	88.6	
09-June -15	9:18:45	85.0	85.6	
09-June -15	9:19:45	83.1	85.2	
09-June -15	9:20:45	83.5	84.1	
09-June -15	9:21:45	83.9	85.2	
09-June -15	9:22:45	84.4	85.3	
09-June -15	9:23:45	83.1	84.2	
09-June -15	9:24:45	81.4	83.2	
09-June -15	9:28:30	83.7	84.9	King Pile #3
09-June -15	9:29:30	84.4	85.7	
09-June -15	9:30:30	84.1	85.4	
09-June -15	9:31:30	83.1	89.9	
09-June -15	9:32:30	82.8	83.8	
09-June -15	9:33:30	84.7	83.9	
09-June -15	9:34:30	84.9	86.9	
09-June -15	9:35:30	85.8	86.1	
09-June -15	9:36:30	87.3	88.3	
09-June -15	9:37:30	82.8	86.2	
09-June -15	9:44:09	84.2	85.3	King Pile #4
09-June -15	9:45:09	83.5	86.6	
09-June -15	9:46:09	88.2	88.8	
09-June -15	9:47:09	83.9	88.7	
09-June -15	9:48:09	83.3	88.8	
09-June -15	9:49:09	90.6	91.6	
09-June -15	9:50:09	91.5	93	
09-June -15	9:51:09	92.8	94.6	
09-June -15	9:52:09	86.4	91.2	
09-June -15	9:55:18	81.5	83.8	King Pile #5
09-June -15	9:56:18	83.9	86.6	
09-June -15	9:57:18	85.1	85.8	
09-June -15	9:58:18	86.0	86.7	
09-June -15	9:59:18	81.0	82.5	
09-June -15	10:00:18	80.9	81.5	
09-June -15	10:01:18	81.8	82.5	
09-June -15	10:02:18	82.4	83.1	
09-June -15	10:03:18	80.0	83	

Date	Time (EDT)	LA_{eq} (dB re 20 μPa)	LA_{max} (dB re 20 μPa)	Notes
09-June -15	10:07:13	83.4	85.2	King Pile #6
09-June -15	10:08:13	84.2	86.6	
09-June -15	10:09:13	86.1	86.8	
09-June -15	10:10:13	81.1	86.2	
09-June -15	10:11:13	80.8	81.6	
09-June -15	10:12:13	81.5	82	
09-June -15	10:13:13	82.4	83	
09-June -15	10:14:13	78.9	83.3	
09-June -15	10:15:13	80.1	83.9	
09-June -15	10:17:00	82.4	86.9	King Pile #7
09-June -15	10:18:00	88.4	90	
09-June -15	10:19:00	85.7	87	
09-June -15	10:20:00	85.8	93.1	
09-June -15	10:21:00	91.9	92.6	
09-June -15	10:22:00	85.5	86.4	
09-June -15	10:23:00	85.1	86.4	
09-June -15	10:24:00	93.2	94.4	
09-June -15	10:25:00	87.8	94.5	
09-June -15	10:26:00	84.4	86.9	
09-June -15	10:27:00	85.4	86.2	
09-June -15	10:28:00	88.4	94.4	
09-June -15	10:29:00	94.1	94.9	
09-June -15	10:30:00	90.0	94	
09-June -15	10:31:00	86.3	87.6	
09-June -15	10:32:00	84.9	85.5	
09-June -15	10:33:00	85.5	86.1	
09-June -15	10:34:00	85.4	86.9	
09-June -15	10:35:00	78.1	79.4	
09-June -15	10:36:00	82.3	93.1	
09-June -15	10:37:00	85.7	86.5	
09-June -15	10:38:00	89.0	94	
09-June -15	10:39:00	93.3	94	
09-June -15	10:40:00	86.1	87	
09-June -15	10:41:00	85.8	86.6	
09-June -15	10:42:00	86.1	86.6	
09-June -15	10:43:00	90.1	94.4	
09-June -15	10:44:00	93.0	93.5	
09-June -15	10:45:00	90.7	93.5	
09-June -15	10:46:00	86.7	87.4	
09-June -15	10:47:00	86.0	87	
09-June -15	10:48:00	86.3	87	
09-June -15	10:49:00	86.0	86.7	

Date	Time (EDT)	LA_{eq} (dB re 20 µPa)	LA_{max} (dB re 20 µPa)	Notes
09-June -15	10:50:00	86.4	87.2	
09-June -15	10:51:00	87.6	94	
09-June -15	10:52:00	91.8	93.1	
09-June -15	10:53:00	85.4	86.9	
09-June -15	10:54:00	85.9	86.9	
09-June -15	10:55:00	85.0	85.5	
09-June -15	10:56:00	85.0	85.9	
09-June -15	10:57:00	84.8	85.3	
09-June -15	10:58:00	89.8	93	
09-June -15	10:59:00	90.1	91.4	
09-June -15	11:00:00	85.1	85.9	
09-June -15	11:01:00	83.9	84.9	
09-June -15	11:02:00	83.4	84.4	

Table C-7. One Minute A-Weighted Airborne Data, JEB Little Creek, 10 - 11 September 2015 (Shaded cells are when pile driving occurred)

Date	Time (EDT)	LAeq (dB re 20 µPa)	LZmax (dB re 20 µPa)	Notes
10 September 2105	10:15:00	86.5	96.1	Pile #1
10 September 2105	10:16:00	86.3	100.6	
10 September 2105	10:17:00	86.4	95.1	
10 September 2105	10:18:00	85.8	95.2	
10 September 2105	10:19:00	84.3	91.1	
10 September 2105	10:20:00	85.0	92.7	No Pile Driving
10 September 2105	10:21:00	84.9	91.2	
10 September 2105	10:22:00	84.8	91.0	
10 September 2105	10:23:00	84.7	91.1	
10 September 2105	10:24:00	85.2	100.0	
10 September 2105	10:25:00	79.4	98.7	
10 September 2105	10:26:00	77.3	90.9	
10 September 2105	10:27:00	82.6	98.3	Pile #2
10 September 2105	10:28:00	87.7	102.3	
10 September 2105	10:29:00	87.0	95.7	
10 September 2105	10:30:00	86.5	94.2	
10 September 2105	10:31:00	86.6	95.5	
10 September 2105	10:35:00	80.0	91.4	No Pile Driving
10 September 2105	10:36:00	79.9	91.2	
10 September 2105	10:37:00	79.1	90.5	
10 September 2105	10:38:00	79.4	91.9	
10 September 2105	10:39:00	80.1	93.2	
10 September 2105	10:40:00	79.8	93.8	
10 September 2105	10:41:00	80.6	103.7	
10 September 2105	10:42:00	74.2	88.9	
10 September 2105	10:43:00	74.1	90.2	
10 September 2105	10:44:00	79.4	95.8	
10 September 2105	10:45:00	82.9	97.0	Pile #3
10 September 2105	10:46:00	82.8	96.3	
10 September 2105	10:47:00	82.7	96.2	
10 September 2105	10:48:00	75.7	95.0	
10 September 2105	10:49:00	73.9	98.8	No Pile Driving
10 September 2105	10:50:00	72.8	94.4	
10 September 2105	10:51:00	72.7	88.8	
10 September 2105	10:52:00	73.5	90.3	
10 September 2105	10:53:00	73.1	88.1	
10 September 2105	10:54:00	72.7	92.3	
10 September 2105	10:55:00	72.4	91.1	
10 September 2105	10:56:00	72.8	88.3	
10 September 2105	10:57:00	73.1	89.1	

Date	Time (EDT)	LAeq (dB re 20 µPa)	LZmax (dB re 20 µPa)	Notes
10 September 2105	10:58:00	72.7	87.7	
10 September 2105	10:59:00	74.0	95.2	
10 September 2105	11:00:00	69.5	91.1	
10 September 2105	11:01:00	70.1	90.8	
10 September 2105	11:02:00	74.1	91.2	
10 September 2105	11:03:00	74.2	92.1	
10 September 2105	11:04:00	77.0	95.3	
10 September 2105	11:05:00	83.2	98.4	Pile #4
10 September 2105	11:06:00	82.0	96.8	
10 September 2105	11:07:00	74.3	93.6	No Pile Driving
10 September 2105	11:08:00	74.7	90.6	
10 September 2105	11:09:00	73.8	90.1	
10 September 2105	11:10:00	73.5	93.0	
10 September 2105	12:36:00	86.1	95.5	
10 September 2105	12:37:00	86.3	91.1	
10 September 2105	12:38:00	86.4	91.4	
10 September 2105	12:39:00	86.5	91.4	
10 September 2105	12:40:00	86.1	94.6	
10 September 2105	12:41:00	81.1	96.1	
10 September 2105	12:42:00	80.7	93.0	
10 September 2105	12:43:00	84.7	99.4	Pile #6
10 September 2105	12:44:00	82.6	94.9	
10 September 2105	12:45:00	84.1	97.4	
10 September 2105	12:46:00	84.4	96.4	
10 September 2105	12:47:00	82.1	95.0	No Pile Driving
10 September 2105	12:48:00	86.1	99.1	
10 September 2105	12:49:00	85.8	93.8	
10 September 2105	12:50:00	85.5	95.4	
10 September 2105	12:51:00	84.0	94.6	
10 September 2105	12:52:00	83.6	94.6	
10 September 2105	12:53:00	84.1	93.7	
10 September 2105	12:54:00	84.1	93.5	
10 September 2105	12:55:00	84.7	94.9	
10 September 2105	12:56:00	84.3	94.9	
10 September 2105	12:57:00	79.3	96.5	
10 September 2105	12:58:00	78.9	92.2	
10 September 2105	12:59:00	78.7	99.9	
10 September 2105	13:00:00	84.0	99.1	Pile #7
10 September 2105	13:01:00	84.0	95.1	
10 September 2105	13:02:00	82.3	95.6	

Date	Time (EDT)	LAeq (dB re 20 µPa)	LZmax (dB re 20 µPa)	Notes
10 September 2105	13:03:00	83.2	96.0	No Pile Driving
10 September 2105	13:04:00	83.7	94.7	
10 September 2105	13:05:00	83.4	95.9	
10 September 2105	13:06:00	83.4	94.7	
10 September 2105	13:07:00	84.4	96.3	
10 September 2105	13:08:00	81.2	98.1	
10 September 2105	13:09:00	79.2	94.4	
10 September 2105	13:10:00	81.7	96.8	Pile #8
10 September 2105	13:11:00	83.4	96.5	
11 September 2015	8:52:00	81.6	94.3	No Pile Driving
11 September 2015	8:53:00	86.3	99.7	
11 September 2015	8:54:00	90.4	105.9	
11 September 2015	8:55:00	85.6	96.3	
11 September 2015	8:56:00	80.2	95.8	
11 September 2015	8:57:00	79.9	96.7	
11 September 2015	8:58:00	80.1	105.1	
11 September 2015	8:59:00	80.4	103.5	
11 September 2015	9:00:00	79.9	94.7	
11 September 2015	9:01:00	79.9	95.8	
11 September 2015	9:02:00	84.6	99.9	
11 September 2015	9:03:00	80.3	99.7	
11 September 2015	9:04:00	85.6	100.3	
11 September 2015	9:05:00	90.3	101.6	Pile A
11 September 2015	9:06:00	88.1	98.8	
11 September 2015	9:07:00	80.6	99.1	No Pile Driving
11 September 2015	9:08:00	80.7	98.1	
11 September 2015	9:09:00	80.7	100.8	
11 September 2015	9:10:00	81.3	99.3	
11 September 2015	9:11:00	82.3	105.1	
11 September 2015	9:12:00	82.1	98.9	
11 September 2015	9:13:00	81.7	100.9	Pile B
11 September 2015	9:14:00	81.8	101.9	
11 September 2015	9:15:00	81.5	100.0	
11 September 2015	9:16:00	81.7	100.8	No Pile Driving
11 September 2015	9:17:00	81.0	102.4	
11 September 2015	9:18:00	80.2	102.5	
11 September 2015	9:19:00	83.2	101.9	
11 September 2015	9:20:00	80.6	97.8	
11 September 2015	9:21:00	80.5	97.9	
11 September 2015	9:22:00	85.9	98.4	
11 September 2015	9:23:00	86.4	99.2	

Date	Time (EDT)	LAeq (dB re 20 µPa)	LZmax (dB re 20 µPa)	Notes
11 September 2015	9:24:00	81.1	99.5	Pile C
11 September 2015	9:25:00	81.2	99.5	
11 September 2015	9:26:00	81.9	99.5	
11 September 2015	9:27:00	81.9	103.2	No Pile Driving
11 September 2015	9:28:00	80.7	98.8	
11 September 2015	9:29:00	82.2	100.2	
11 September 2015	9:30:00	77.8	106.1	
11 September 2015	9:31:00	85.0	106.3	
11 September 2015	9:32:00	81.6	106.2	
11 September 2015	9:33:00	86.3	105.4	
11 September 2015	9:34:00	90.4	101.2	
11 September 2015	9:35:00	85.6	98.8	
11 September 2015	9:36:00	80.2	99.6	
11 September 2015	9:37:00	79.9	104.3	
11 September 2015	9:38:00	80.1	101.3	
11 September 2015	9:39:00	80.4	98.6	
11 September 2015	9:40:00	79.9	102.1	
11 September 2015	9:41:00	79.9	104.1	
11 September 2015	9:42:00	84.6	102.8	
11 September 2015	9:43:00	80.3	102.7	Pile D
11 September 2015	9:44:00	85.6	108.2	
11 September 2015	9:45:00	90.3	107.7	No Pile Driving
11 September 2015	9:46:00	88.1	108.0	
11 September 2015	9:47:00	80.6	111.6	
11 September 2015	9:48:00	80.7	109.5	
11 September 2015	9:49:00	80.7	100.6	
11 September 2015	9:50:00	81.3	107.7	
11 September 2015	9:51:00	82.3	106.6	Pile E

Table C-8. One Minute A-Weighted Airborne Data (dB re 20 µPa), JEB Little Creek, 26 -27 April 2016 (Shaded cells are when pile driving occurred)

Date	Time (EDT)	LA_{seq} (dB re 20 µPa)	LZ_{imax} (dB re 20 µPa)	Notes
26 April 2016	13:53:00	78.4	79.7	No Pile Driving
26 April 2016	13:54:00	101.3	106.4	Pile #1
26 April 2016	13:55:00	101.9	106.0	
26 April 2016	13:56:00	99.9	102.6	
26 April 2016	13:57:00	99.7	102.5	
26 April 2016	13:58:00	99.6	102.1	
26 April 2016	13:59:00	98.7	101.5	
26 April 2016	14:00:00	98.8	102.1	
26 April 2016	14:01:00	97.8	101.1	
26 April 2016	14:02:00	96.2	98.9	No Pile Driving
26 April 2016	14:03:00	91.1	98.0	
26 April 2016	14:04:00	79.8	82.6	
26 April 2016	14:05:00	77.0	79.0	
26 April 2016	14:06:00	76.3	77.3	
26 April 2016	14:07:00	76.2	77.6	
26 April 2016	14:08:00	101.0	106.6	Pile #2
26 April 2016	14:09:00	102.3	105.5	
26 April 2016	14:10:00	101.1	104.2	
26 April 2016	14:11:00	100.3	103.2	
26 April 2016	14:12:00	100.5	103.2	
26 April 2016	14:13:00	100.0	103.1	
26 April 2016	14:14:00	97.4	101.8	
26 April 2016	14:15:00	95.4	98.4	No Pile Driving
26 April 2016	14:16:00	95.7	99.0	
26 April 2016	14:17:00	95.4	98.1	
26 April 2016	14:18:00	88.1	97.7	
26 April 2016	14:19:00	78.2	82.2	
26 April 2016	14:20:00	73.6	78.3	
26 April 2016	14:21:00	73.1	74.6	
26 April 2016	14:22:00	102.0	104.3	Pile #3
26 April 2016	14:23:00	101.2	105.3	
26 April 2016	14:24:00	99.5	102.5	
26 April 2016	14:25:00	97.5	101.1	
26 April 2016	14:26:00	97.6	102.0	
26 April 2016	14:27:00	96.7	100.4	
26 April 2016	14:28:00	95.9	99.7	No Pile Driving
26 April 2016	14:29:00	93.6	96.5	
26 April 2016	14:30:00	93.3	96.0	
27 April 2016	10:43:00	78.1	79.4	
27 April 2016	10:44:00	98.3	102.3	Pile #4
27 April 2016	10:45:00	93.7	100.9	

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