February
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Final

Hydroacoustic and Airborne Noise Monitoring at the Naval Station Norfolk during Pile Driving – Interim Report

21 October through 27 October 2014

Naval Station Norfolk ,Norfolk, VA

Interim Report Prepared by

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Under Contract to

HDR

Environmental, Operations and Construction, Inc.

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Summary

This report summarizes the underwater and airborne noise monitoring results for impact driving 24-inch (61 centimeter) square concrete piles and vibratory driving timber piles at the Naval Station Norfolk in Norfolk, Virginia (**Figure 1**). The piles driven were fender piles, nonstructural, being driven to upgrade the fender system at Pier 4. The water depth at the pile locations was approximately 40 feet (12 meters). 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. There are approximately 400 to 750 feet (122 to 229 meters) between the piers. 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 being driven adjacent to the south side of Pier 4. We attempted to measure the levels from the water jetting/drilling during the installation of the concrete piles; however, the noise levels from the jetting/drilling were low and there was a high number of vessels moving about the area, creating a higher noise level than the jetting. The concrete piles were installed, after the jetting/drilling, using a Vulcan model 010 drop hammer. The timber piles were installed using a vibratory hammer. For measurement locations, please refer to **Figure 2**.

On 21 October, noise monitoring was conducted on five 24-inch (61 centimeter) square concrete fender piles. Measurements were attempted for both the jetting/drilling installation and impact driving. All the piles were first installed using a water jet/drill. The piles were then driven to their final tip elevation using a Vulcan 010 drop hammer with an energy rating of 44.1 kilojoules (kj) (32,500 foot-pounds [ft-lbs]). The peak sound pressure level (SPL), root mean square (RMS) level, sound exposure level (SEL), and cumulative SEL (cSEL) were measured at two locations: a near location ranging from 18 feet (7 meters) to 33 feet (11 meters) and a distant location ranging from approximately 127 feet (50 meters) to 140 feet (55 meters). The driving times were very short, ranging from 1 to 19 pile strikes per pile. Underwater sound levels are reported as Z-weighted[1] levels in decibels (dB) referenced to one micro pascal (µPa) with the exception of SEL and cSEL that are referenced to 1 μPa^2-sec. Airborne sounds are A-weighted levels in dB referenced to 20 µPa. There were a high number of boats (naval security and work boats) moving about the area, which made it difficult to measure the jetting/drilling operations at both locations. During the impact driving, these were not so problematic because the noise levels from the impact driving were higher than the boat noise.

At the closer measurement site, there was a problem with the hydrophone connector that created random internal noise. Because of the short driving times, there was not enough time to replace the hydrophone. This problem was resolved and the next driving period was captured on 25 October.

From 22 October through 24 October, work was suspended on the project due to high winds and very high tides. Part of the time the crane could not work due to the high winds, and when the winds did subside, the tides were too high for the crew to work on the template needed to set the remainder of the concrete piles.

[1] Z-weighting is a flat response applied to underwater sound measurements made over the frequency range of 10 to 20,000 Hz. A-weighting includes adjustments to measured airborne sounds over the same frequency range, adjusted to reflect the perceived loudness to humans.

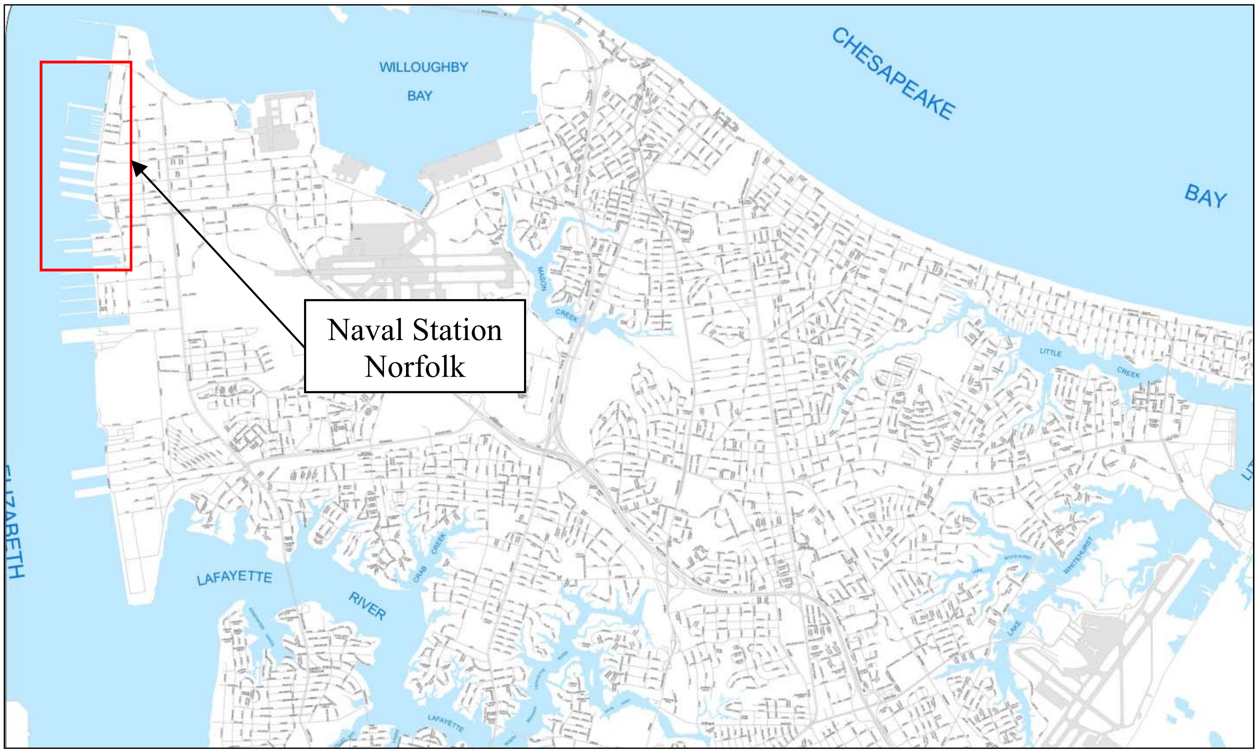

Figure 1: Study Location Map

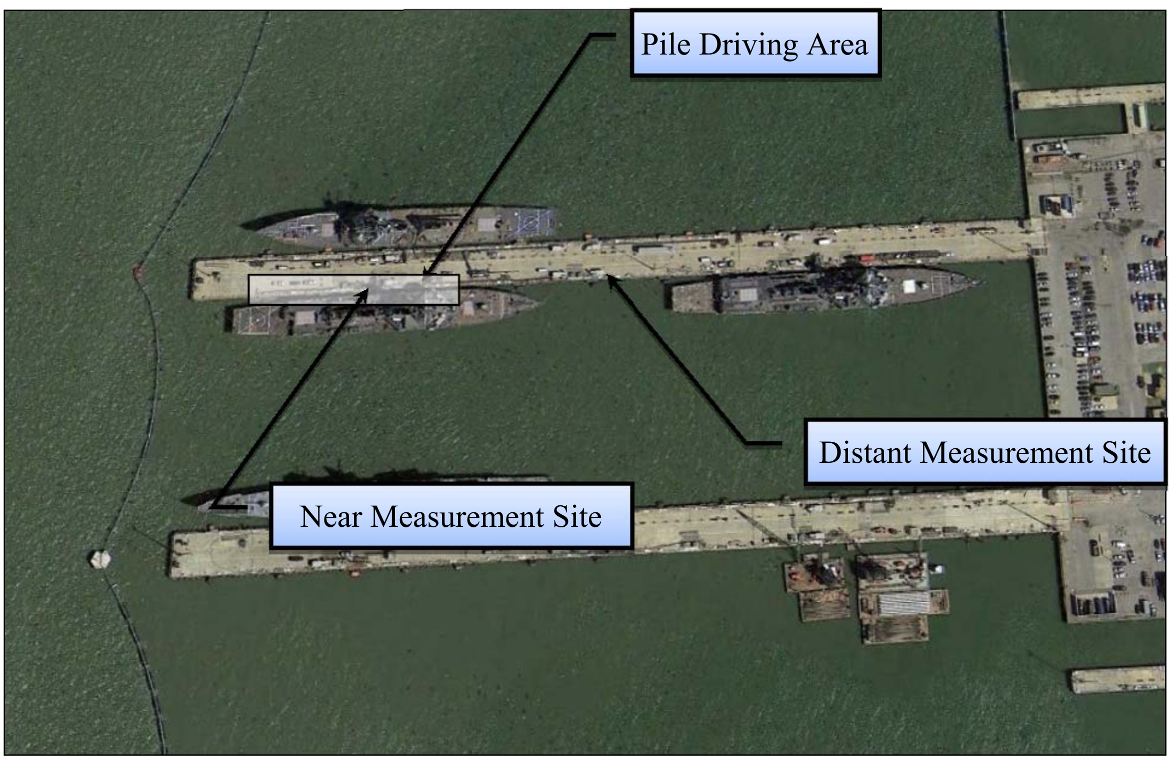

Figure 2: Measurement Locations

On 25 October, sound measurements were conducted on five 24-inch (61 centimeter) square concrete fender piles. Measurements were attempted for both the jetting/drilling installation and impact driving. All the piles were first installed using a water jet/drill. The piles were then driven to their final tip elevation using a Vulcan 010 drop hammer with an energy rating of 44.1 kj (32,500 ft-lbs). The peak SPL, RMS level, SEL, and cSEL sound levels were measured at two locations. The driving times were slightly longer than those on 21 October, ranging from 22 to 49 pile strikes.

On 27 October, nine timber piles were installed using a vibratory hammer. For the timber pile, installation measurements were made at two locations: the closer ranged from 30 feet (9 meters) to 75 feet (23 meters) and the farther from 145 feet (44 meters) to 1,246 feet (75 meters). These pile installation events were very short, ranging from 18 seconds to 65 seconds. The measured noise levels for the last three piles installed were higher than the previous piles installed. During the installation of these piles, the vibratory hammer began to smoke, which indicated that there was more resistance to the piles being installed. There may have been either some underwater obstructions or a different type of substrate. At this time, it is unknown what actually caused the increase in noise levels.

Table 1 provides a data summary of sound pressure levels at the near location for the impact pile driving measured on 21 and 25 October. **Table 2** and **Table 3** provide a data summary of maximum and average 1-second RMS and the maximum and average 10-second average RMS sound pressure levels for the vibratory pile driving measured during the installation of the timber piles on 27 October.

Table 1: Data Summary of Levels from Impact Driving 24-inch (61 centimeters) Square Concrete Piles (dB re: 1µPa)[3]

Date	Distance feet (meters)	Number of Blows	Peak		RMS		SEL[1]		cSEL[1]
			Average	Range	Average	Range	Average	Range	
10/21/2014	164 ft (50 m)	19	170	169-174	158	144-162	145	135-151	162
10/21/2014	167 ft (51 m)	11	168	167-171	154	136-158	140	128-149	--[2]
10/21/2014	171 ft (52 m)	9	167	166-167	155	152-158	137	121-148	--[2]
10/21/2014	174 ft (53 m)	4	168	166-169	149	149-159	138	127-149	--[2]
10/21/2014	177 ft (54 m)	17	168	167-173	157	151-160	139	123-151	163
10/25/2014	30 ft (9 m)	23	184	181-186	174	171-176	164	156-165	178
10/25/2014	33 ft (10 m)	29	185	184-186	175	171-177	165	164-166	180
10/25/2014	36 ft (11 m)	30	185	184-186	176	174-177	166	165-167	181
10/25/2014	39 ft (12 m)	49	184	182-186	175	171-177	165	162-167	182
10/25/2014	43 ft (13 m)	76	184	183-185	174	170-176	164	158-166	183

[1] dB re: 1 µPa^2-sec
[2] Based on NMFS guidance, single strike SELs less than 150 dB do not accumulate to cause injury to fish.
[3] On 10/21/2014 there was a malfunction with the 10 meter location hydrophone located, it calibrated in the morning and was damaged on site during setup, did not have time to replace.

Table 2: Data Summary of RMS Vibratory Driving Levels for Timber piles Measured at 29 feet (9 meters) to 75 feet (23 meters) (dB re: 1µPa)

Distance	Date	Duration (mm:ss)	1-second RMS		10-second RMS	
			Range	Average	Range	Average
23	10/27/2014	1:05	134-142	137	136-139	138
19	10/27/2014	1:22	135-144	138	137-142	139
17	10/27/2014	0:37	135-141	138	137-138	138
13	10/27/2014	0:41	141-160	149	145-159	149
11	10/27/2014	0:26	160-166	163	163-164	163
10	10/27/2014	0:18	159-164	162	162-162	162
12	10/27/2014	0:31	158-168	163	163-163	163
10	10/27/2014	0:34	158-166	165	163-166	165
9	10/27/2014	0:24	163-170	165	165-156	165

Table 3: Data Summary of RMS Vibratory Driving Levels for Timber piles Measured at 144 feet (44 meters) to 246 feet (75 meters) (dB re: 1µPa)

Distance	Date	Duration (mm:ss)	1-second RMS		10-second RMS	
			Range	Average	Range	Average
50	10/27/2014	1:05	125-130	128	121-129	127
46	10/27/2014	1:22	127-132	129	128-130	129
44	10/27/2014	0:37	127-132	130	126-132	130
75	10/27/2014	0:41	128-136	132	130-135	132
72	10/27/2014	0:26	136-140	138	137-138	137
70	10/27/2014	0:18	138-142	139	139-140	139
68	10/27/2014	0:31	134-140	136	136-136	136
65	10/27/2014	0:34	134-140	138	136-136	136
63	10/27/2014	0:24	136-142	137	137-138	137

Attachment A shows the time history of the pile driving and typical one-third octave band spectra.

Airborne measurements were also conducted at a fixed location from the pile driving. On 21, 25 and 27 October, the distance to the pile driving was maintained at 50 feet (15 meters). These measured levels are shown in **Attachment B**.

Measurement Equipment

Reson Model TC-4013 and Reson Model TC-4033 hydrophones were used for the underwater measurements. The signal from the hydrophones was fed directly into a Larson Davis Laboratories (LDL) Model 831 Precision Sound Level Meter (LDL 831). The measurement system was calibrated prior to use in the field with a G.R.A.S. Type 42AA Pistonphone and hydrophone coupler. The pistonphone, when used with the hydrophone coupler, produces a continuous 136.4 dB (re 1 µPa) tone at 250Hz. The SLM is calibrated to this tone prior to use in the field. The tone is then measured by the SLM and is recorded on to the beginning of the digital audiotapes that were used in the field. The system calibration status was checked at the end of the measurement event by both measuring the calibration tone and recording the post-measurement tone on tape. Signal analysis included the measurement of the calibration tone at the beginning and end of tape recording events. All systems were found to be within 0.5 dB of the calibration levels. The pistonphone output has been certified at an independent facility.

Airborne measurements were made using a 0.5-inch (1.3 centimeter) G.R.A.S. Model 40AQ pre-polarized random-incidence microphone. The signal was fed into an LDL Model 820 Sound Level Meter. The system was calibrated with a LDL Model CAL200 Acoustic Calibrator. The microphone was calibrated at the beginning and end of each day. Pre-event and post-event calibration levels were within 0.1 dB.

Underwater Sound Descriptors

The acoustic monitoring for this project reports data in several 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.

During impact driving, the maximum peak sound pressures (LZ_{peak}), impulse RMS sound pressure level (LZI), and the 1-second SEL (LZ_{eq}) were measured underwater "live" using the LDL 831. During vibratory driving, the maximum peak sound pressures (LZ_{peak}) and the fast RMS sound pressure level (LZF) were measured underwater "live" using the LDL 831. The LDL 831 Sound Level Meter (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 acoustic impulses were performed using the LDL 831 SLMs as well. The LDL 831 captures the signal and stores the measurement data retrieved at the completion of a day of measurements.

Airborne Sound Descriptors

A-weighted airborne data were collected for both impact and vibratory driving. During data collection, 1-second and 1-minute intervals were used for measuring airborne data. The airborne data shown on the various time history charts represent the 1-second "fast" A-weighted RMS (L_{max}), which uses a 125-millisecond time constant for RMS averaging. The tables shown in **Attachment B** show the 1-minute data, including the 1-minute LA_{eq} and 1-minute LA_{max}, and the peak sound pressure level.

Underwater Sound Data Management

Data were collected from hydrophones and recorded on Larson Davis 831 SLMs. The measurements of peak, RMS, and SEL sound pressures for each second were recorded. For each day of measurements, digital data captured by the SLMs were downloaded to a computer. The SLMs were used to provide accurate live readings and spectra data. These readings were recorded in field notebooks from time to time.

Quality Control

The measurement system was calibrated prior to use in the field with a G.R.A.S. Type 42AA pistonphone and hydrophone coupler. The pistonphone, when used with the hydrophone coupler, produces a continuous 136.4 or 145.3 dB (referenced to 1 μPa) tone at 250 Hertz (Hz). The SLM is calibrated to this tone prior to use in the field. The tone is then measured by the SLM and is recorded onto the beginning of the digital audiotapes that were used in the field. The system calibration status was checked at the end of the measurement event by measuring the calibration tone and recording the post-measurement tone. Signal analysis included the measurement of the calibration tone at the beginning and end of recording events. All systems were found to be within 0.1 dB of the calibration levels. The pistonphone output was 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), system gain settings, and the equipment used to make each measurement. Notebook entries were copied after each measurement day and filed for safekeeping. Recorded media were labeled and stored for subsequent analysis.

Discussion and Recommendations

Upon analyzing the data in detail, 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 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 higher than expected and could be attributed two likely factors: hammer type and the fact that the piles were shorter and non-bearing. 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.

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. Based on the attenuation rate of $31*Log_{10}$, the distance to the marine mammal Level B harassment zone would be between 262 feet (80 meters) and 820 feet (250 meters).

Overall, with the exception of the first day of measurements where the near hydrophone failed, the measurements for the impact driving of the concrete piles and the vibratory installation of the timber piles were fairly uneventful. The measurements made for the jetting/drilling of the concrete piles was less than successful primarily due to the high ambient noise (working boats in the area). Steps have been made to ensure that there is an extra hydrophone in the field that is calibrated to the system to allow for a rapid exchange in the unlikely event of another hydrophone failure.

Glossary

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

Cumulative sound exposure level (SELcumulative) – In an evaluation of pile driving impacts on fish, it may be necessary to estimate the cumulative SEL associated with a series of pile strike events. SELcumulative 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:

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

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 micro-Pascal (μPa), and for air it is 20 micro-Pascals (the threshold of healthy human audibility).

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

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

LZF - Z-weighted, Fast, Sound Level

LZI –Z-weighted impulse RMS sound pressure level

LZ_{eq} - Z-weighted, Leq, Sound Level

LZ_{peak} – Z-weighted peak sound level

Peak sound pressure level (LPEAK) – The largest absolute value of the instantaneous sound pressure. This pressure is expressed as a decibel (referenced to a pressure of 1 micro-Pascal [μPa] for water and 20 μPa for air) or in units of pressure, such as μPa or PSI.

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.

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 and can be described manual, 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.

Sound pressure level (SPL) – An expression of the sound pressure using the decibel (dB) scale and the standard reference pressures of 1 micro-Pascal (μPa) for water and biological tissues, and

20 μPa for air and other gases. Sound pressure is the sound force per unit area, usually expressed in micro-Pascals (or micro-Newtons 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 decibels as 20 times the logarithm to the base 10 of the ratio between the pressure exerted by the sound to a reference sound pressure (e.g., 20 micro-Pascals). SPL is the quantity that is directly measured by a sound level meter. Measured in decibels (dB).

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

ATTACHMENT A:

TIME HISTORY OF PILE DRIVING AND ONE-THIRD OCTAVE BAND SPECTRA

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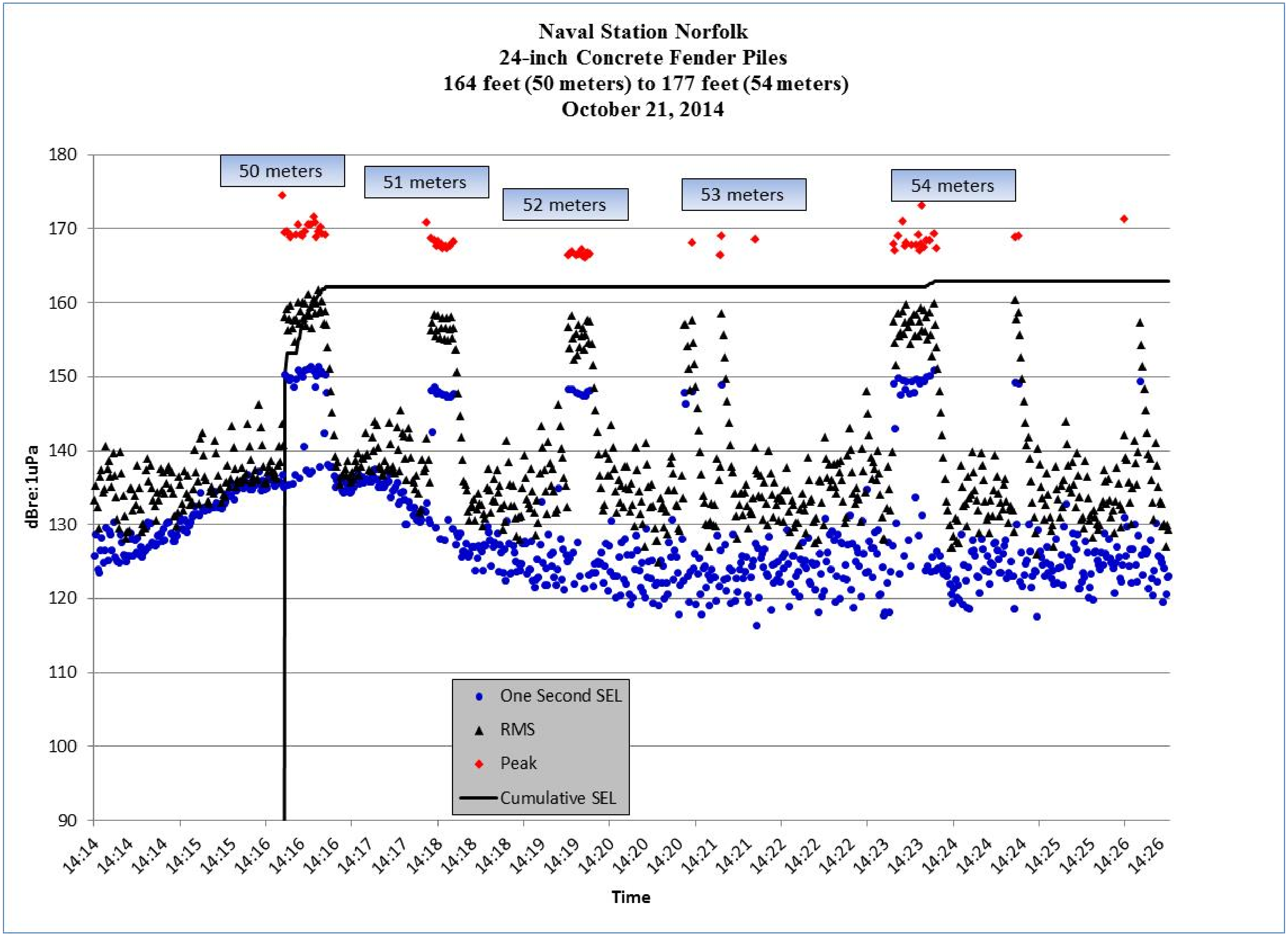
Naval Station Norfolk
24-inch Concrete Fender Piles
164 feet (50 meters) to 177 feet (54 meters)
October 21, 2014
50 meters
51 meters
52 meters
53 meters
54 meters
180
170
160
150
140
130
120
110
100
90
dBre:1uPa
One Second SEL
RMS
Peak
Cumulative SEL
14:14
14:14
14:14
14:15
14:15
14:16
14:16
14:16
14:17
14:17
14:18
14:18
14:18
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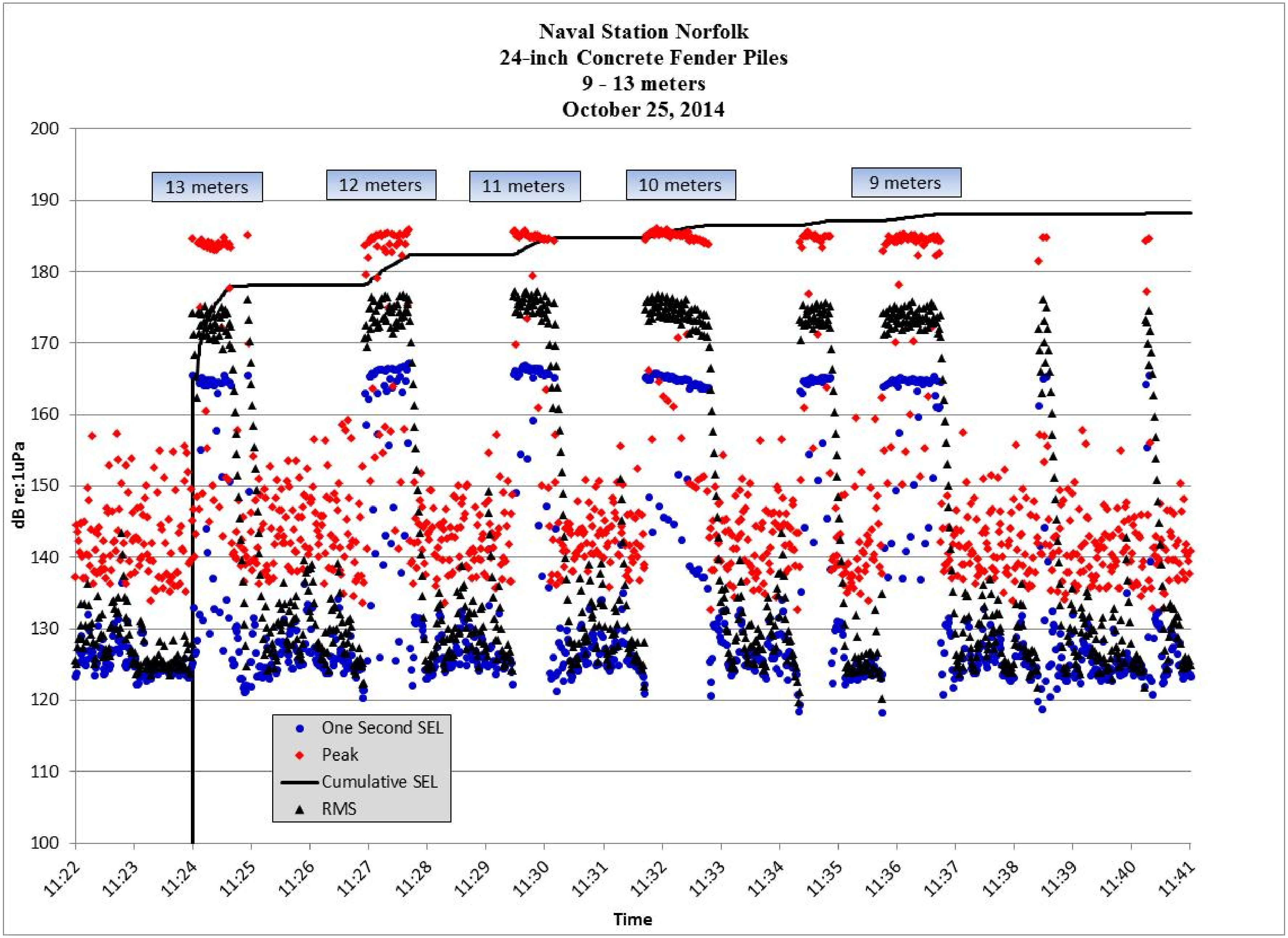
14:26
14:26
Time


Naval Station Norfolk
24-inch Concrete Fender Piles
9 - 13 meters
October 25, 2014
13 meters
12 meters
11 meters
10 meters
9 meters
dB re:1uPa
200
190
180
170
160
150
140
130
120
110
100
11:22
11:23
11:24
11:25
11:26
11:27
11:28
11:29
11:30
11:31
11:32
11:33
11:34
11:35
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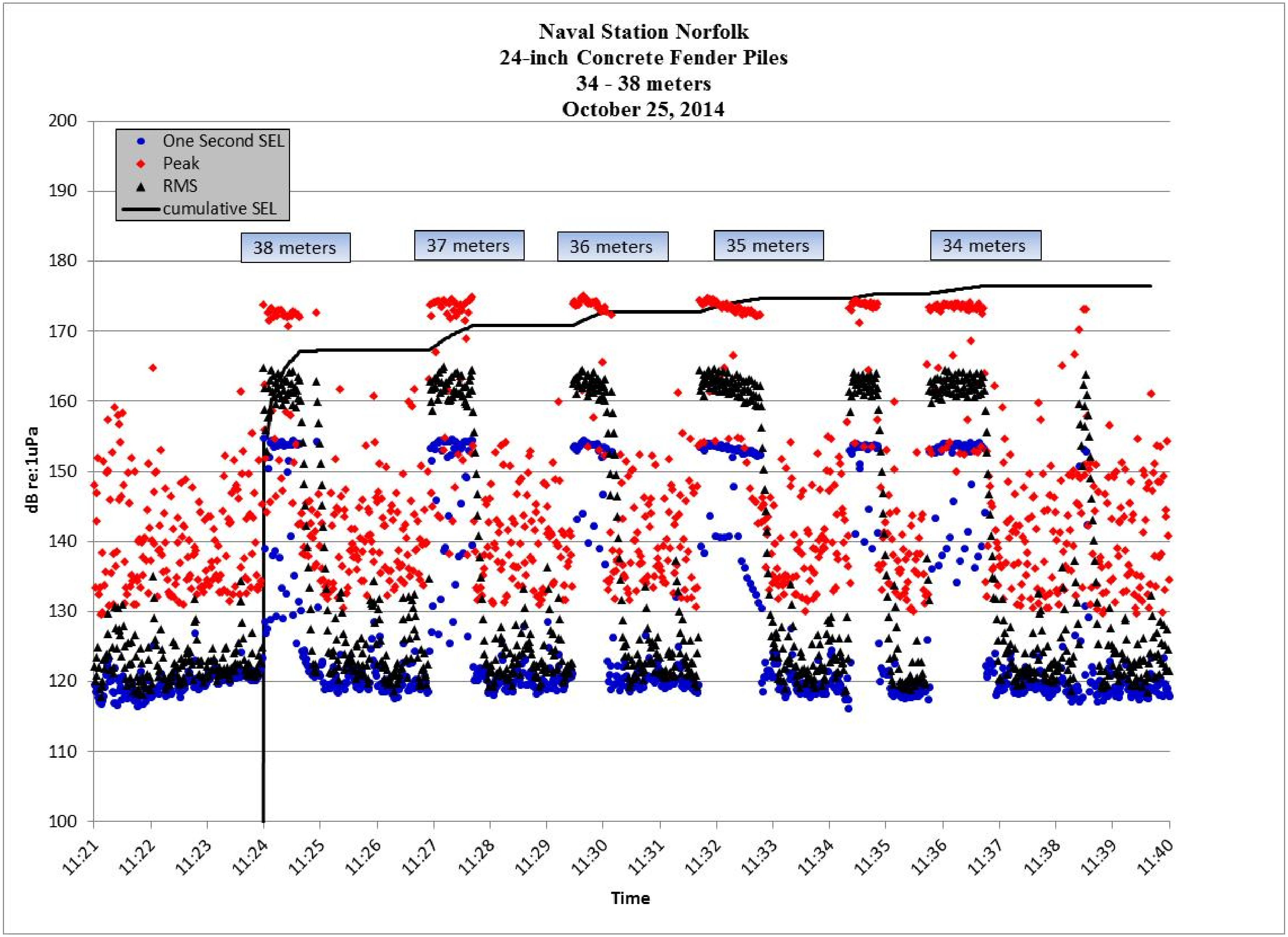
11:39
11:40
11:41
Time
One Second SEL
Peak
Cumulative SEL
RMS


Naval Station Norfolk
24-inch Concrete Fender Piles
34 - 38 meters
October 25, 2014
One Second SEL
Peak
RMS
cumulative SEL
38 meters
37 meters
36 meters
35 meters
34 meters
dB re:1uPa
200
190
180
170
160
150
140
130
120
110
100
11:21
11:22
11:23
11:24
11:25
11:26
11:27
11:28
11:29
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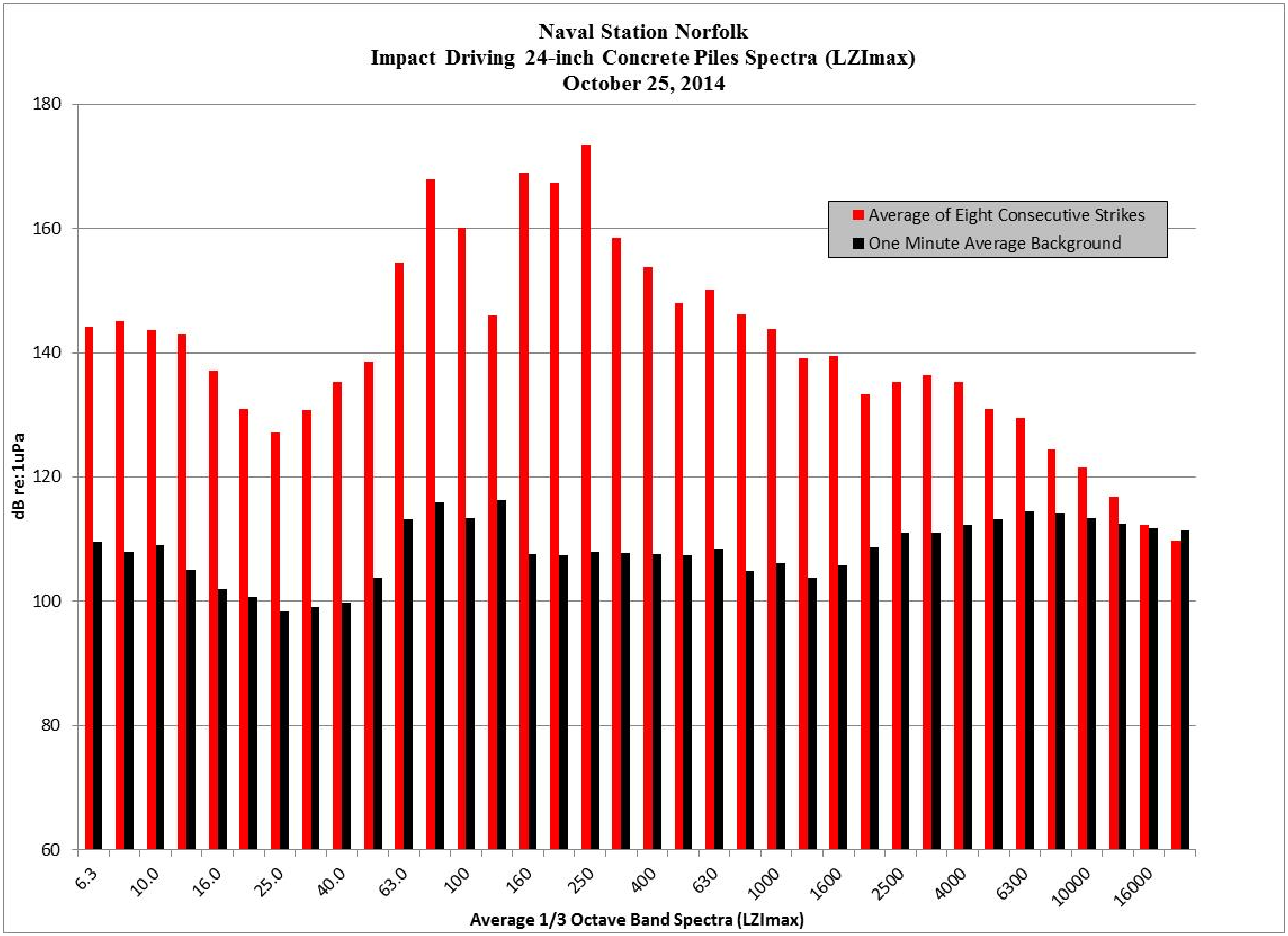
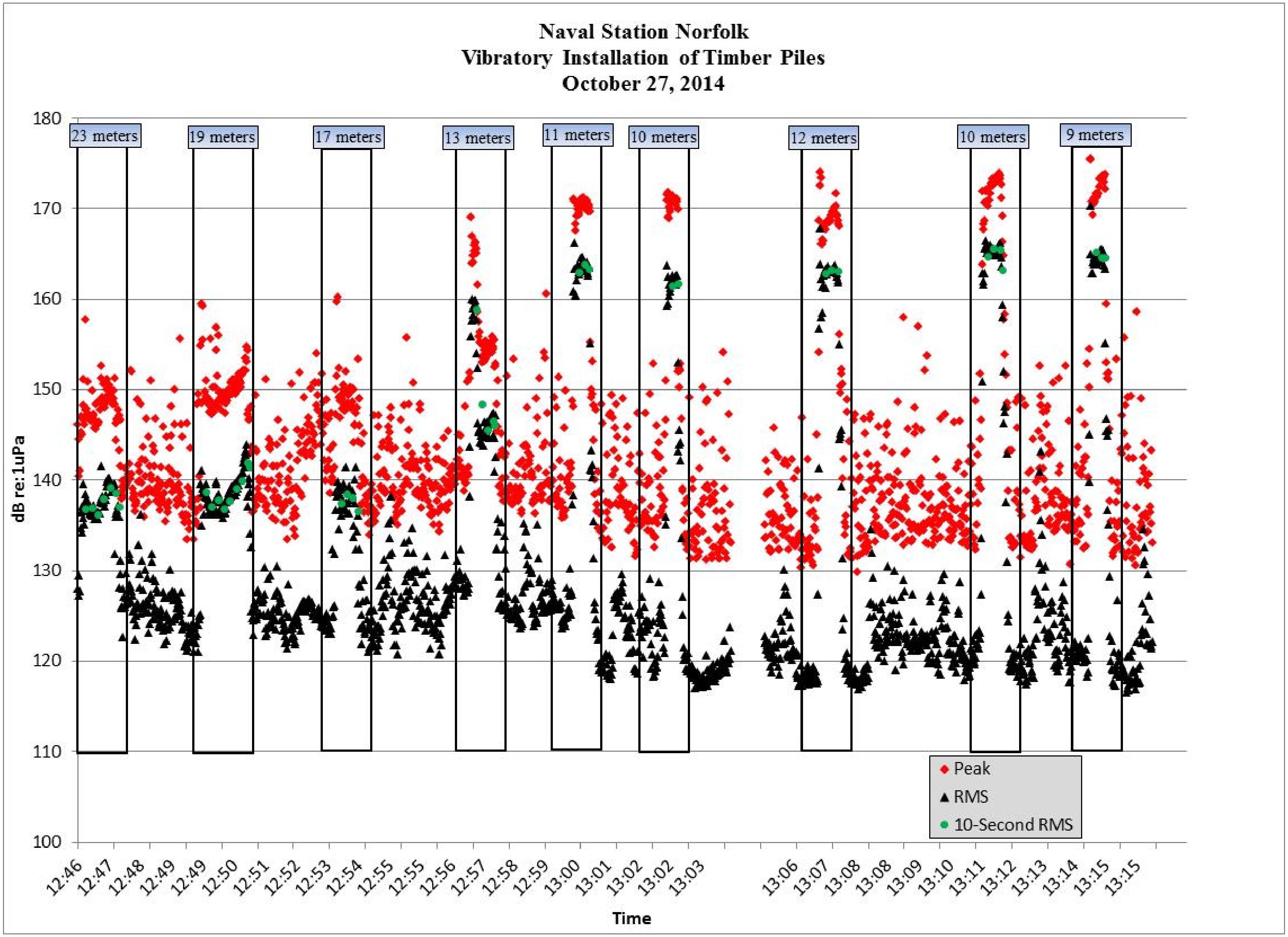
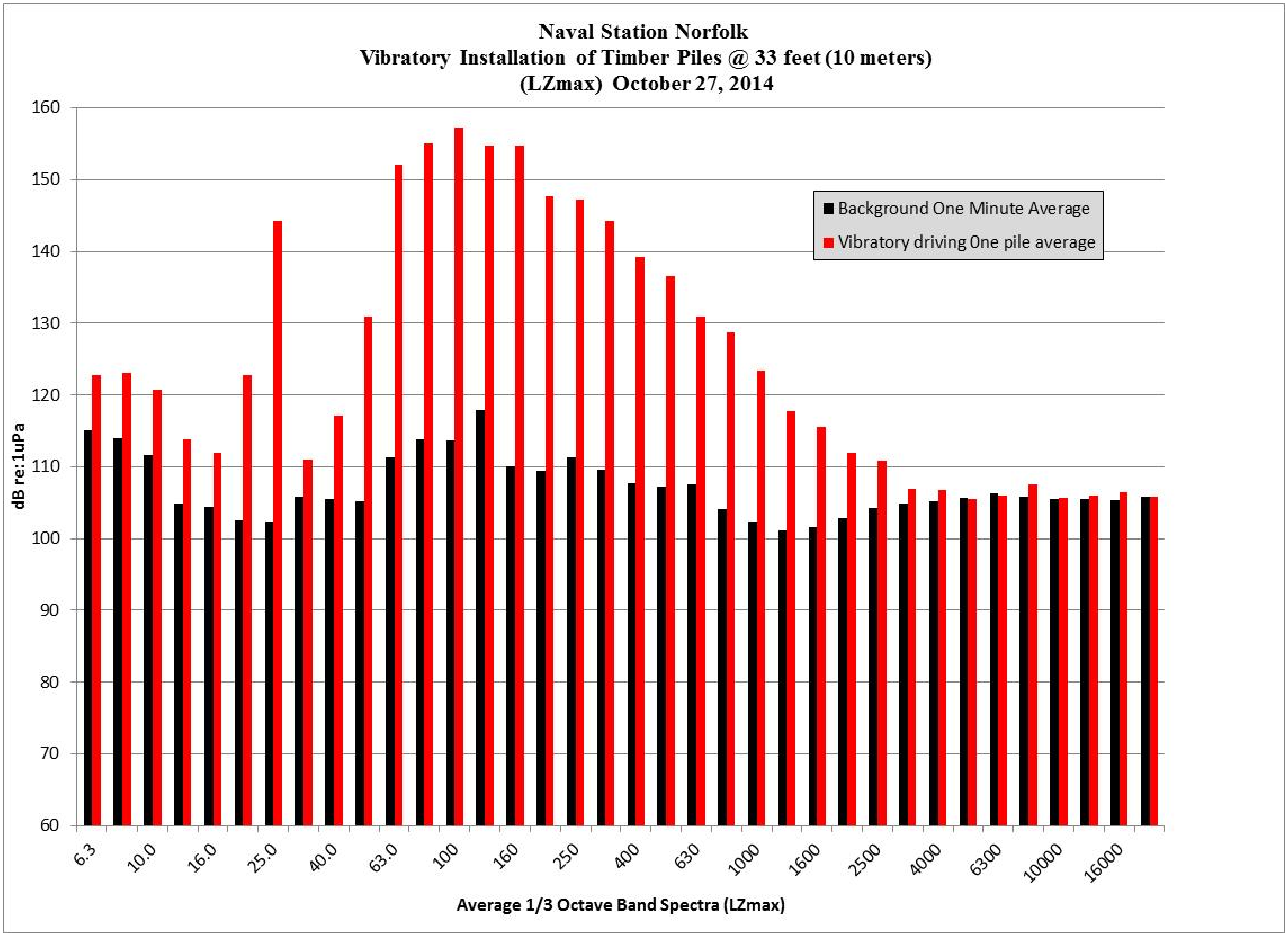
11:39
11:40
Time


Naval Station Norfolk
Impact Driving 24-inch Concrete Piles Spectra (LZImax)
October 25, 2014
Average of Eight Consecutive Strikes
One Minute Average Background
dB re:1uPa
180
160
140
120
100
80
60
6.3
10.0
16.0
25.0
40.0
63.0
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Average 1/3 Octave Band Spectra (LZImax)


Naval Station Norfolk
Vibratory Installation of Timber Piles
October 27, 2014
23 meters
19 meters
17 meters
13 meters
11 meters
10 meters
12 meters
10 meters
9 meters
dB re:1uPa
Time
Peak
RMS
10-Second RMS


Naval Station Norfolk
Vibratory Installation of Timber Piles @ 33 feet (10 meters)
(LZmax) October 27, 2014
dB re:1uPa
160
150
140
130
120
110
100
90
80
70
60
Background One Minute Average
Vibratory driving One pile average
6.3
10.0
16.0
25.0
40.0
63.0
100
160
250
400
630
1000
1600
2500
4000
6300
10000
16000
Average 1/3 Octave Band Spectra (LZmax)

ATTACHMENT B:

ONE-MINUTE AIRBORNE DATA

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Table B-1.1. One Minute A-Weighted Airborne Data

Date	Time	L_{eq}	L_{max}
Impact Driving			
10/21/2014	14:12:00	79.6	82.3
10/21/2014	14:15:00	80.6	88.6
10/21/2014	14:16:00	79.9	84.8
10/21/2014	14:17:00	96.5	101.6
10/21/2014	14:18:00	92.6	100.1
10/21/2014	14:19:00	84.8	99.5
10/21/2014	14:20:00	93.8	102.5
10/21/2014	14:21:00	87.3	98.4
10/21/2014	14:22:00	83.3	97.7
10/21/2014	14:23:00	75.8	76.5
10/21/2014	14:24:00	94.6	100
10/21/2014	14:25:00	89.1	101.4
10/21/2014	14:26:00	83.8	100.2
10/21/2014	14:27:00	82.2	97.7
10/21/2014	14:28:00	81.3	88.7
10/21/2014	14:29:00	77.6	82.5
10/25/2014	11:21:00	66.7	71.7
10/25/2014	11:22:00	70.2	83.6
10/25/2014	11:23:00	83.9	100.2
10/25/2014	11:24:00	96.7	101.7
10/25/2014	11:25:00	68.7	80.8
10/25/2014	11:26:00	86.8	100.2
10/25/2014	11:27:00	96.2	100.5
10/25/2014	11:28:00	67.2	74
10/25/2014	11:29:00	97.3	102.4
10/25/2014	11:30:00	87.6	100.3
10/25/2014	11:31:00	95.5	101.7
10/25/2014	11:32:00	98.3	101.7
10/25/2014	11:33:00	69.4	75.2
10/25/2014	11:34:00	98.2	102.5
10/25/2014	11:35:00	93.6	100.7
10/25/2014	11:36:00	98	100.8
10/25/2014	11:37:00	69.5	75.3
10/25/2014	11:38:00	87.7	99.8
10/25/2014	11:39:00	73	87.6
10/25/2014	11:40:00	86.4	99.6
10/25/2014	11:41:00	69.5	73.7

Table B-1.2. One Minute A-Weighted Airborne Data

Date	Time	L_{eq}	L_{max}
Vibratory Driving			
10/27/2014	12:43:00	65.8	76
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
10/27/2014	12:47:00	82.3	84.5
10/27/2014	12:48:00	75.1	84.1
10/27/2014	12:49:00	80.8	85.5
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
10/27/2014	12:53:00	81.4	86.2
10/27/2014	12:54:00	77.8	85.6
10/27/2014	12:55:00	77.9	82.4
10/27/2014	12:56:00	79.6	83.4
10/27/2014	12:57:00	83.8	87.6
10/27/2014	12:58:00	77.7	84.6
10/27/2014	12:59:00	79.9	83.2
10/27/2014	13:00:00	83.3	87.1
10/27/2014	13:01:00	78.5	83.4
10/27/2014	13:02:00	81.2	86.4
10/27/2014	13:03:00	78.4	86.3
10/27/2014	13:04:00	75.2	82.9
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
10/27/2014	13:08:00	78.4	83.4
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
10/27/2014	13:12:00	79.3	85.8
10/27/2014	13:13:00	80.1	83.6
10/27/2014	13:14:00	83.6	86.3
10/27/2014	13:15:00	75.1	84.3
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