Description of Underwater Noise Attenuation System
Design Unit 7
for the
New NY Bridge Project

Revision 2
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1.0 Introduction

The Pile Load Test (PLT) Program includes an underwater noise monitoring program for the installation of the test piles. The purpose of this noise monitoring program is to confirm that the underwater noise attenuation system (NAS) intended for use during production impact pile driving achieves its design goal of minimizing (to the maximum extent practicable) the effects of underwater sound on fishes in the Hudson River. This program is being conducted pursuant to the following New NY Bridge project requirements:

- New York State Thruway Authority (NYSTA) Tappan Zee Hudson River Crossing Project DB Contract Document Part 3 Project Requirements, Section 3 (P3PR3) Environmental Compliance, Conformed November 2012 and other applicable sections;
- New York State Department of Environmental Conservation (NYSDEC) DEC ID 3-9903-00043/00012-0014 (NYSDEC Permit); and
- National Marine Fisheries Service (NMFS) Biological Opinion (BO) April 10, 2013.

Underwater noise monitoring is conducted to verify that the NAS is deployed and operating in accordance with design specifications and determine compliance with underwater noise attenuation requirements.

Tappan Zee Constructors, LLC, (TZC) provided NYSTA and NYSDEC a report titled *Description of Pile Load Test Program and Underwater Noise Attenuation System for the Tappan Zee Hudson River Crossing (PLT-NAS Description)* in July 2013 that compared the NASs that were considered based on the 2012 Pile Installation Demonstration Program (PIDP) and described the multi-tier bubble curtain which was selected for further testing. The *PLT-NAS Description* indicates the following criteria are being used to determine the effectiveness of the NAS:

1. Attenuation – System has achieved at least a 10 dB single strike sound exposure level (SELss) reduction or attenuation during impact pile driving;
2. Ensonified Area – System has attenuated underwater noise to achieve the distances to the required NMFS and NYSDEC thresholds during pile driving established by the NMFS BO Term and Condition 9 and NYSDEC Permit Condition 14; and
3. System Operation and Compatibility – System can be safely deployed and retrieved repeatedly during production pile driving without impact to pile driving requirements and project schedule.

The *PLT-NAS Description* demonstrated that the multi-tier bubble curtain can achieve at least a 10 dB SEL attenuation during impact pile driving and that the system could be safely deployed and retrieved repeatedly during production pile driving. As such, the multi-tier bubble curtain was selected for further testing during test pile installation. The report also provided a plan for testing the NAS, to determine whether or not the required distances to the NMFS and NYSDEC thresholds are being achieved.

Test pile installation monitoring results provide guidance on operational specifications of the NAS monitoring, as well as the monitoring locations for production pile driving. The purpose of this report is to provide the results of the underwater noise monitoring during installation of test piles for the Design Unit 7 (see Attachment 1) and based on those results, provide the design plans and anticipated operational specifications for the NAS for Design Unit 7 in accordance with the following NYSDEC Permit requirements:

8. The results of sound attenuation tests conducted during the 2012 Pile Installation Demonstration Program (PIDP);and any additional test results from underwater sound attenuation studies during the 2013 PIDP2 will be used to determine the most effective underwater sound attenuation system. An underwater sound attenuation system or

systems must be deployed during driving of steel piles [redacted] to minimize to the maximum extent practicable the effects of underwater sound upon fishes in the Hudson River.

9. At least 30 days before starting installation of permanent piles [redacted] within each specific in-river design unit (as identified in the March 21, 2013 letter) the Permittee must give the Department design plans and operational specifications for the underwater sound attenuation system for that design unit. Except for piles installed during the 2013 PIDP2, installation of piles [redacted] may begin when the Department has given written approval of the underwater sound attenuation system for each in-river design unit. Upon Department approval the final sound attenuation plan will be posted on the project website maintained by the Permittee.

2.0 Installation of Test Piles

The Pile Load Test Program utilizes test piles in each of the ten (10) Design Units plus the Main Span (eleven [11] total design units), with the primary purpose to confirm pile load capacities. Design Unit 7 consists of Piers 26 to 29 (see Attachment 2). The foundation for Pier 29 will consist of [redacted] piles while the foundations for Pier 26 to 28 will consist of [redacted] piles. The installations of test piles were completed with an IHC S-800 impact hammer. A summary of test pile installations for Design Unit 7 is provided in Table 1.

Table 1. Summary of Test Pile Installation for the NAS for Design Unit 7

Test Pile	Pile Diameter	Impact Hammering Date
PLT 112L	[redacted]	7/31/2013
PLT 112	[redacted]	8/3/2013
PLT 111	[redacted]	8/19/2013
PLT 110	[redacted]	9/6/2013
PLT 112RE	[redacted]	9/16/2013

3.0 Unconfined Multi-tier Bubble Curtain NAS Design

Based on the NAS effectiveness determination in the *PLT-NAS Description*, the unconfined multi-tier bubble curtain was selected for further testing during test-pile installation. Refer to Attachment 3, Drawings 1UBCR through 10UBCR, for engineering details on the system.

3.1 NAS Components

The unconfined multi-tier bubble curtain consists of aluminum bubbler rings suspended from the pile-driving template at four points, spaced a maximum of 10 feet vertically, and connected to each other using ½"-diameter wire rope. See Attachment 3 for bubbler ring dimensions and details including hole diameter, spacing, and orientation for the NAS for 4-ft and 6-ft piles.

The aluminum ring is connected to a dedicated compressor (Figures 1). This compressor is connected to a reservoir tank to allow a continuous supply of air throughout pile driving (Figure 2). During the installation of test piles, a flow meter and air pressure gauge were used to measure air flow and air pressure (Figure 3). The air compressor is capable of supplying an air pressure of up to 100 pounds per square inch (psi) or

an air flow of 1600 cubic feet per meter (cfm) to each bubbler ring (Attachment 4). The reservoir tank allows the system to supply an air flow of up to 2000 cfm, to each bubbler ring, as was demonstated during testing.

Figure 1. Air Compressors and Reservoir Tanks on the Air Compressor Barge

Figure 2. Reservoir Tanks on the Air Compressor Barge

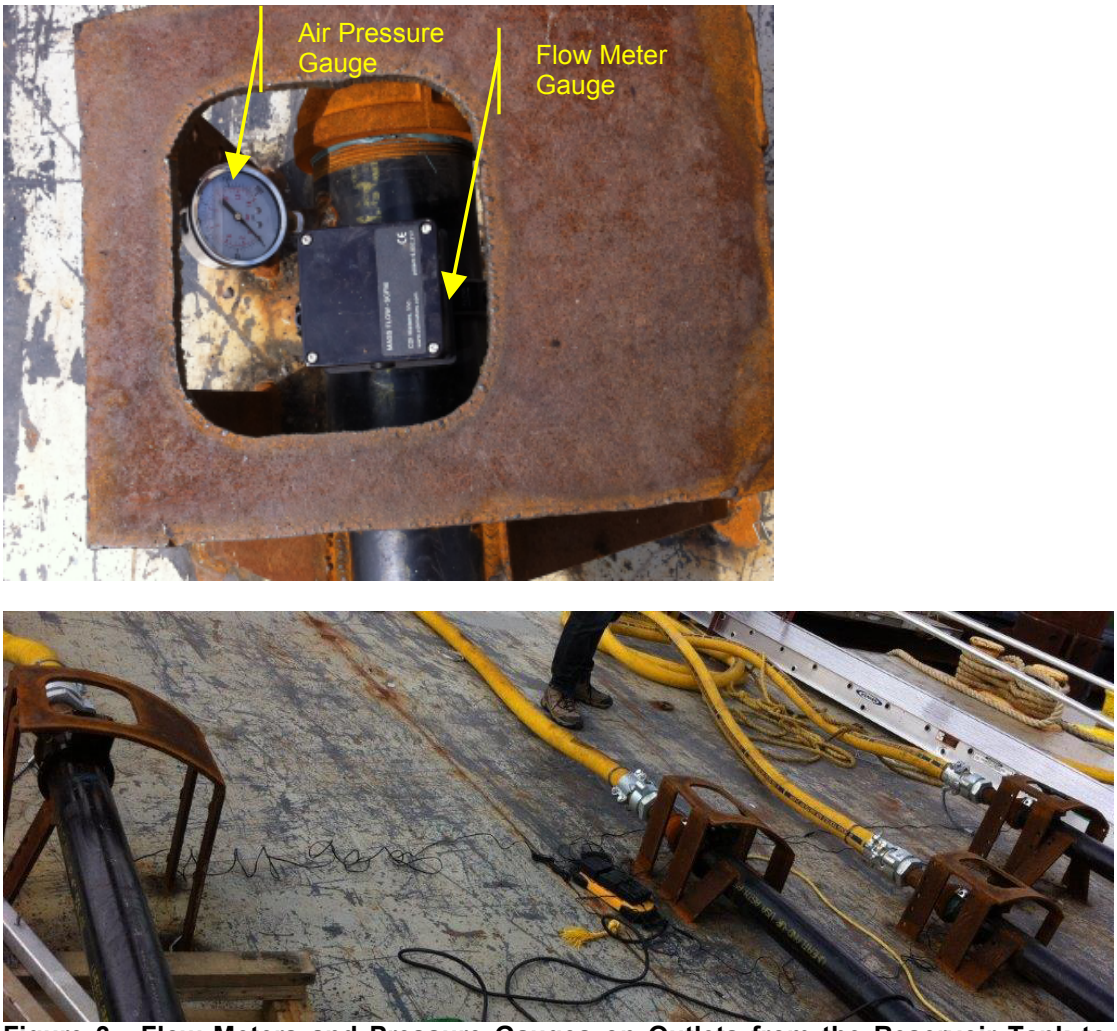

Figure 3. Flow Meters and Pressure Gauges on Outlets from the Reservoir Tank to the Bubbler Rings

3.2 NAS Deployment and Operation

The NAS deployment and operation proceeded as expected. After the piles were driven with the vibratory hammer, the bubble curtain rings were deployed around the perimeter of the piles with a crane and hung from the secondary template using wire rope slings and shackles (Figure 4). The air compressors/reservoir tanks pumped air into the rings (Figure 5), the impact hammer was lofted, the piles were tapped (i.e., a series of minimal energy strikes), and then driven to the required depth.

Figure 4. Deployment of the Unconfined Multi-tier Bubble Curtain

Figure 5. Operation of the Multi-tier Bubble Curtain

4.0 Underwater Noise Monitoring During Test Pile Installation

4.1 Methods

Details of the equipment, the calibration of the equipment, the data collected, and the signal processing for underwater monitoring are included in the Underwater Noise Monitoring Plan. Details on the underwater noise monitoring for PLT 112L, PLT 112, PLT 111, PLT 110, and PLT 112RE are provided in the Daily Memoranda for each day of pile driving (Attachment 1).

Figure 6a and Figure 6b illustrate typical barge and hydrophone set up for [redacted] piles. As seen in Figure 6a and Figure 6b, a real time Autonomous Multichannel Acoustic Recorder (AMAR-RT) and several Autonomous Multichannel Acoustic Recorders (AMARs) were generally placed at the distances of the noise level thresholds predicted in the NMFS BO (although locations varied based on conditions, such as vessel traffic and tides), as follows:

- peak SPL (sound pressure level) – located on the barge or survey vessel, approximately 100 feet from the pile for 6-ft piles and 33 feet for [redacted] piles, based on the distance from the pile to the 206 re 1 µPa peak SPL isopleth
- cSEL (cumulative Sound Exposure Level) - located approximately 505 feet from the pile for [redacted] piles and 132 feet for [redacted] piles, based on the distance from the pile to the 187 dB re 1 μPa^2-s cSEL isopleth
- rms SPL (root mean square SPL) – located approximately 800 feet from the pile for [redacted] piles and 400 feet for [redacted] piles, based on the distance from the pile to the 150 dB re 1µPa rms SPL

The AMAR-RT was continuously monitored through-out pile installation while data collected from the AMARs was downloaded following piling.

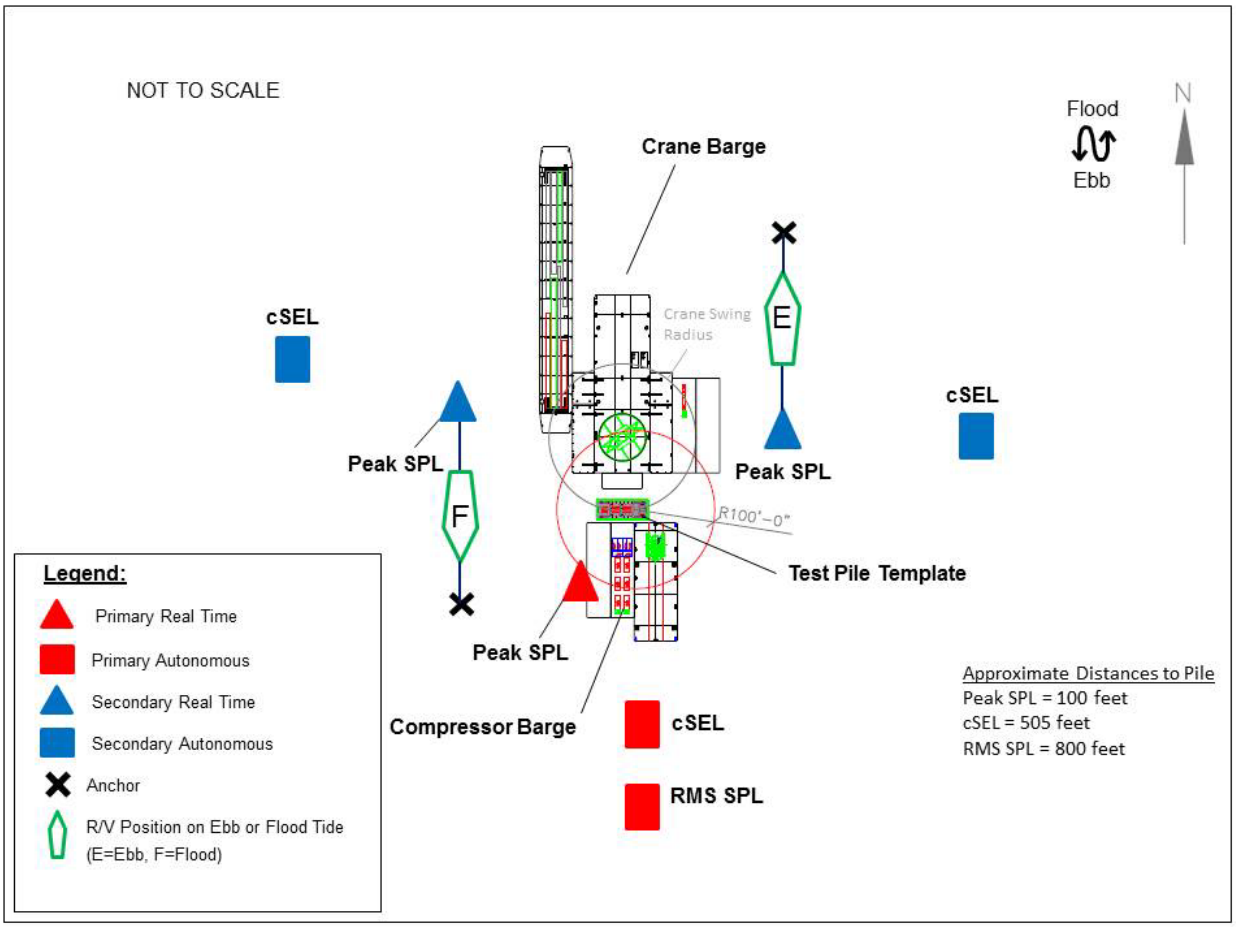

Figure 6a. Plan View of a Typical Test Pile Barge Arrangement and Hydrophone Locations for [redacted] Piles

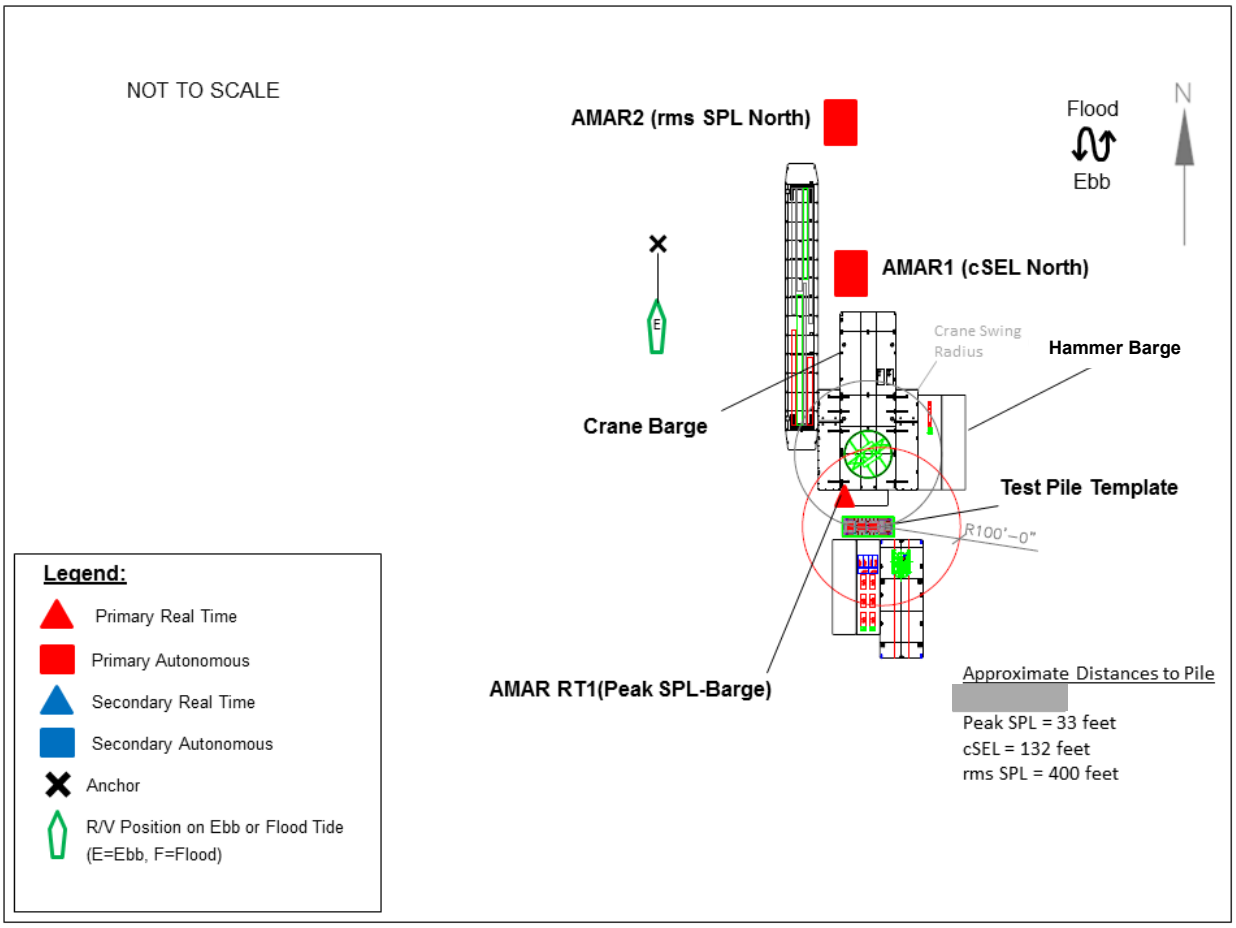

Figure 6b. Plan View of a Typical Test Pile Barge Arrangement and Hydrophone Locations for Piles

Test pile installation for Design Unit 7 occurred during a variety of river current conditions (ebb, flood, and slack current). Hydrophones were placed strategically to capture variation in the performance of the NAS relative to the river current and barge placement.

During the installation of PLT 112L the currents were 1-2 knots in a flood current. The hydrophones were located up current and cross current at a several ranges. PLT 112 was installed during an ebb current of 0.6 to 2.0 knots. The hydrophones for test pile PLT 112 were strategically placed up-current, down-current, and cross-current to test the NAS in multiple directions. PLT 111 was installed during a flood and slack currents of 0 to 1.6 knots. The hydrophones completely surrounded the test pile during the PLT 111 to test the NAS in all directions. PLT 110 was installed during a 0.5-1.6 knot ebb current with hydrophones in up-current and cross-current positions. PLT 112RE was installed during an ebb current of 0.8-2.2 knots and all hydrophones were placed in up current positions. Table 2 provides a summary of the underwater noise monitoring equipment deployment and position relative to the current for the driving of the test piles associated with Design Unit 7.

Table 2. Equipment Deployment and Position Relative to Current During Installation of Test Piles for Design Unit 7

Date Test Pile No.	Hydrophone ID	Location Relative to Pile[1]	Location Relative to Current	Current During Pile Driving	Distance to Pile (ft)	Water depth (ft)
7/31/2013 PLT 112L	AMAR-RT 11	Peak SPL- Barge	Up-current	Flood (1 – 2 knots)	95	40
	AMAR-RT 12	Peak SPL- Vessel	Cross-current		270	31
	AMAR-221	cSEL South	Up-current		556	41
	AMAR-222	cSEL East	Cross-current		598	20
	AMAR-228	RMS SPL East	Cross-current		776	18
8/3/2013 PLT 112	AMAR-RT 11	Peak SPL- Barge	Down-current	Ebb (0.6 – 2.0 knots)	100	40
	AMAR-RT 12	Peak SPL- Vessel	Cross-current		170	34
	AMAR-221	cSEL East	Cross-current		282	31
	AMAR-222	cSEL North	Up-current		365	36
	AMAR-228	cSEL South	Down-current		238	40
8/19/2013 PLT 111	AMAR-RT 11	Peak SPL- Barge	Up-Current	Flood (1.6 – 0 knots)	125	34
	AMAR-RT 12	Peak SPL- Vessel	Cross-Current		141	40
	AMAR-221	cSEL South	Up-current		396	45
	AMAR-222	cSEL West	Cross-current		268	39
	AMAR-228	cSEL North	Down-current		502	40
9/6/2013 PLT 110	AMAR-RT 11	Peak SPL- Barge	Up-current	Ebb (0.5 – 1.6 knots)	33	18
	AMAR-175	cSEL 100’ East	Cross-current		132	18
	AMAR-221	cSEL 200’ East	Cross-current		221	18
	AMAR-228	rms SPL 300’ East	Cross-current		389	20
9/16/2013 PLT 112RE	AMAR-RT-11	Peak SPL Barge	Up-current	Ebb (0.8 – 2.2 knots)	34	38
	AMAR-175	cSEL North	Up-current		304	36
	AMAR-228	rms SPL North	Up-current		581	36

[1]Locations correspond to the hydrophone locations labeled in Figures 6a and 6b and are based on the following:

- peak SPL – located on the barge or survey vessel based on the distance from the pile to the 206 re 1 µPa peak SPL isopleth per the NMFS BO April 10, 2013.
- cSEL- located based on the distance from the pile to the 187 dB re 1 μPa^2-s cSEL isopleth per the NMFS BO April 10, 2013.
- rms SPL – located based on the distance from the pile to the 150 dB re 1µPa rms SPL isopleth per the NMFS BO April 10, 2013.

The tests for this design unit were informed by the previous tests of the NAS where air flow was varied throughout pile driving by never independently of other variables, such as impact hammer energies or tidal conditions. All tests were performed at a range of tidal conditions and hammer energies which could be expected during production pile driving. Table 3 provides the number of rings deployed and the NAS settings during the installation of the 5 test piles.

Table 3. Description of NAS During Installation of Test Piles for Design Unit 7

Date Test Pile No.	Water Depth (ft)	Number of Rings	Air Flow (cfm) per Bubbler Ring	Air Pressure (psi)
7/31/2013 PLT 112L	42	5	900-2000	35-80
8/3/2013 PLT 112	42	5	900-2000	40-70
8/19/2013 PLT 111	42	5	800-2100	40-100
9/6/2013 PLT 110	18	2	1400-1750	60-66
9/16/2013 PLT 112RE	38	5	1250-1400	70

4.2 Results

4.2.1 NMFS Physiological and Behavioral Thresholds

In accordance with the NMFS BO Term and Condition Number 6, the monitoring program estimated: (i) the peak sound pressure level (peak SPL in dB re 1 µPa) at each recorder and the distance from the pile at which the peak SPL exceeds the 206 dB re 1 µPa, (ii) the cSEL at each recorder and the distance from the pile at which the cSEL exceeds 187 dB re 1 $\mu Pa^2 \cdot s$ at the end of pile driving[1], and (iii) the rms SPL at each recorder and the distance from the pile at which rms SPL exceeds 150 dB re 1 µPa.

Table 4 provides a summary of the underwater noise levels measured at each recorder during the test pile installation. Table 5 provides the distances to each of the NMFS BO thresholds. **These results show that the distance to the 206 dB re 1 µPa peak SPL did not exceed NMFS requirement of 200-feet for [redacted] piles and 40-feet for [redacted] piles at Design Unit 7.** The largest diameter to the 206 dB re 1 µPa peak SPL isopleth was 16-feet for [redacted] piles and 13-feet for [redacted] piles, which is similar to or less than the 206 dB re 1 µPa peak SPL results for the NASs tested during the 2012 PIDP. Specifically, during the 2012 PIDP the diameters to the 206 dB re 1 µPa peak SPL isopleth was 15 – 40 feet for [redacted] piles, 76 feet for the [redacted] pile, and 28 feet for the [redacted] pile (Jasco 2012)[2].

Furthermore, the estimated diameter of the 187 dB re 1 μPa^2-s cSEL isopleth at the end of installation of test piles never exceeded 396 ft for [redacted] piles and 140 ft for [redacted] piles. The river width is approximately 15,000 ft; therefore a fish movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving, in accordance with NYSDEC Permit Condition 14.

[1] SEL increases as the number of strikes increases therefore; the diameter of the 187 dB isopleth also reaches a maximum at the end of pile driving.
[2] Jasco. 2012. Underwater Acoustic Monitoring of the Tappan Zee Bridge Pile Installation Demonstration Project.

Table 4. Summary of the Measured Sound Levels at Each Hydrophone During the Installation of Test Piles for Design Unit 7

Date Test Pile No.	Location[1]	Distance to Pile (ft)	Max. peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^2-s)[2]
7/31/2013 PLT 112L	Peak SPL Barge	95	180	181
	Peak SPL Vessel	270	171	166
	cSEL South	556	169	170
	cSEL East	598	164	160
	RMS SPL East	776	157	151
8/3/2013 PLT 112	Peak SPL Barge	100	182	185
	Peak SPL Vessel	170	180	179
	cSEL East	282	179	176
	cSEL North	365	180	175
	cSEL South	238	175	177
8/19/2013 PLT 111	Peak SPL Barge	125	192	188
	Peak SPL Vessel	141	191	192
	cSEL South	396	184	184
	cSEL West	268	186	183
	cSEL North	502	181	181
9/6/2013 PLT 110	Peak SPL Barge	33	192	195
	cSEL 100' East	132	177	180
	cSEL 200' East	221	171	176
	rms SPL 300' East	389	166	166
9/16/2013 PLT 112RE	Peak SPL Barge	34	202	197
	cSEL North	304	184	175
	rms SPL North	581	171	168

[1] Locations correspond to the hydrophone locations labeled in Figures 6a and 6b and are based on the following:

- peak SPL – located on the barge or survey vessel based on the distance from the pile to the 206 re 1 µPa peak SPL isopleth per the NMFS BO April 10, 2013.
- cSEL- located based on the distance from the pile to the 187 dB re 1 µPa^2-s cSEL isopleth per the NMFS BO April 10, 2013.
- rms SPL – located based on the distance from the pile to the 150 dB re 1µPa rms SPL isopleth per the NMFS BO April 10, 2013.

[2] At the completion of pile driving.

Table 5. Estimated Distance from Design Unit 7 Pile Driving to the Noise Levels that Represent NMFS Thresholds

Measurement		Pile Load Test (Pile dia. in feet)				
		PLT 112L (6)	PLT 112 (6)	PLT 111 (6)	PLT 110 (4)	PLT 112RE (6)
Pile Installation Duration (hh:mm)		00:04	00:26	00:20	00:25	00:15
Approximate Diameter (ft) of Isopleth	206 dB re 1 µPa peak SPL	15	6	6	13	16
	187 dB re 1 μPa^2-s cSEL	110	190	396	140	184
	150 dB re 1 µPa rms SPL	728	924	6996*	572	784

*Differences in pulse duration can have a greater effect on rms SPL than peak SPL or SEL. For example, if pulse duration is reduced by half, rms SPL can increase by 3 dB without an equivalent change in peak SPL or SELss. The result is that spreading laws for rms SPL that can result in larger isopleth radii for the 150 dB re 1 µPa threshold.

4.2.2 NAS Performance

4.2.2.1 NAS Performance for [redacted] Piles

The NAS was tested in flood, ebb, and slack currents, with hydrophones at various locations relative to the current (i.e., cross current, up current, and down current) (Table 2a). Current speed ranged from 0 to 2.2 knots. Results over all four piles were variable, although no patterns were detected based on location of the recorder relative to current.

During the installation of PLT 112L air pressure and air flow was varied from 35-80 psi and 900-2000 cfm, respectively. The current remained fairly constant at 1-2 knots during pile driving. Hammer energies were also fairly constant from 135-165 kip-ft. Measured sound levels were slightly higher at the 500-600 ft up current recorder compared to the 500-600-ft cross current recorder during. There were no observable changes in measured sound levels, with variation in air pressure. The results for this pile suggest that orientation to the current affected NAS effectiveness which increased the measured sound levels (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 112L). However, there is no indication that the required NMFS and NYSDEC thresholds were exceeded in any direction.

During the installation of PLT 112 air pressure and air flow ranged from 40-70 psi and 900-2000 cfm, respectively. Current speeds increasing from 0.6 - 2.0 knots did not appear to affect underwater noise levels during pile driving of PLT 112. Hammer energy ranged from approximately 100-500 kip-ft. Measured sound levels increased at the end of pile driving when air pressure was reduced to 40 psi and hammer energy increased by 150 – 350 kip-ft. Sound levels appear to be negatively correlated with the NAS air flow (measured sound levels increase as air flow decreases) or positively correlated with the hammer energy. However, there is no indication that the required NMFS and NYSDEC thresholds were exceeded at the end of pile driving (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 112).

During the installation of PLT 111 air pressure and air flow varied from 40-100 psi and 800 – 2100 cfm, respectively. The current slowed from a 1.6 knot flood current to a slack current during the pile driving activity. Hammer energy ranged from approximately 120-340 kip-ft. Sound levels recorded during the slack current showed a decrease in Peak SPL, rms SPL, and SELss by approximately 10-15 dB at all locations while the hammer energy remained relatively constant (+/- 10 kip-ft). Although variation in sound level with current velocity was noted, there is no indication that the required NMFS and NYSDEC thresholds were exceeded at any point (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 111).

During the installation of PLT 112RE air pressure and air flow remained relatively constant at 70 psi (1250-1400 cfm) during a 1-2.2 knot ebb. Hammer energies ranged from approximately 130-160 kip-ft during pile driving. During the first period of pile driving (13:52-14:05), sound levels appear to be negatively correlated with pile penetration. During the second period of pile driving (14:05-14:23), sound levels appear to increase with hammer energy. However, there is no indication that the required NMFS and NYSDEC thresholds were exceeded even for the two-minute period (13:52-13:54) with the highest mean sound levels (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 112RE).

While the results of the four piles indicate that factors that control propagation are not completely understood, under all propagation conditions the thresholds required by the NMFS BO and NYSDEC permit were not exceeded.

4.2.2.2 NAS Performance for [redacted] Piles

During the installation of the PLT 110 the NAS was tested in an ebb current, with speed ranging from 0.5 to 1.6 knots. Air pressure and air flow was relatively constant at 60-66 psi and 1400 to 1750 cfm, respectively, throughout the installation of PLT 110, except for a brief period where the NAS was inadvertently turned off. Hammer energy was increased independently of river current and NAS air flow. Hammer energies of 125-280 kip-ft were used. Sound levels measured at all hydrophones remained constant throughout the installation of PLT 110 while the NAS was in operation despite variation of the hammer energy. When the NAS was off, the maximum SELss recorded was approximately 180 dB re 1µPa^2•s versus approximately 165 dB re 1µPa^2•s recorded while the NAS was functional (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 110). The thresholds required by the NMFS BO and NYSDEC permit were not exceeded when the NAS was operating during the installation of the PLT 110. The estimated diameter the 206 dB re 1 µPa peak SPL isopleth using only the 15 strikes that occurred in the approximately 11 seconds when the was turned off was 41 feet.

4.3 Conclusions

In accordance with NYSDEC Permit Condition 8, "an underwater noise attenuation system or systems must be deployed during the driving of steel piles [redacted] to minimize to the maximum extent practicable the effects of underwater sound upon fishes in the Hudson River." The PLT-NAS Description concludes that the most effective system is the one that will be capable of attenuating noise to achieve the distance thresholds required by NMFS in the BO and that can be safely deployed and retrieved repeatedly during production pile driving without affecting pile driving requirements and project schedule.

Results of test pile installation indicate that the sound levels due to pile driving with [redacted] and an unconfined multi-tier bubble curtain do not exceed the NMFS and NYSDEC permit requirements. Not only did the system meet the requirements in various tidal conditions and positions relative to the current, as well as for the various NAS settings evaluated the, underwater noise isopleths from pile driving was smaller than anticipated by the NMFS BO. Results indicate that the 206 dB re 1µPa peak SPL isopleth was constrained to distances of [redacted] piles and 6.5 ft for [redacted] piles at Design Unit 7 test pile locations. That is, the largest estimated width of the 206 dB re 1µPa peak SPL isopleth was measure at 16 ft, as compared to the 200-ft predicted by the NMFS BO 6-ft piles; and 13 ft as compared to the 40-ft for [redacted] piles predicted by the NMFS BO. These results indicate that the diameters of the 206 dB re 1 µPa isopleth measured for the [redacted] piles with the multi-tier bubble curtains were smaller than anticipated based on the observations from the 2012 PIDP.

Furthermore, the diameter of the 187 dB re 1 µPa^2-s cSEL isopleth at the end of installation of each pile was never estimated to be more than 400 ft. Therefore, the noise levels across the majority of the river at the construction site would be less than 187 dB cSEL, and would thus provide the required corridor for sturgeon migration through the site.

5.0 NAS Design Plan and Operational Specifications

The installation of the five test piles demonstrated the unconfined multi-tier bubble curtain to be readily and safely deployable and retrievable. Given these logistical attributes, combined with the proven effectiveness at obtaining required distances to NMFS and NYSDEC thresholds, the unconfined multi-tier bubble curtain is considered most effective to minimize harm to fish in the Hudson River, to the maximum extent practicable.

During production pile driving for Design Unit 7, the unconfined multi-tier bubble curtain will be deployed and retrieved in a similar manner to the PLT 112L, 112, 111, 110, and 112RE pile installation. Water depth was approximately 42-ft for PLT 112L, 112, 111 and 112RE and approximately 18-ft for PLT 110. Bubbler rings and compressors will be deployed for each pile, so that vertical spacing in the water column is a maximum of 10 feet or less at mean higher high water (MHHW). That is, the NAS will consist of two bubbler rings if the water depth greater than 10 feet. If the water depth is greater than 20 feet, three bubble rings will be used. The NAS will be deployed according the Construction Work Plan. Table 6 provides the anticipated number of bubble rings to be used at each pier.

Table 6. The Anticipated Number of Bubble Rings to be Used at Each Pier in Design Unit 7

Pier	Water Depth (feet)	Number of Bubble Rings*
25	14-16	2
26	16-18	2
27	16-18	2
28	20-22	2-3
29	30	4

*The number of bubbler rings at specific piles within a pier is subject to change, based on field measurements of water depth during pile installation.

The NAS system contains three valves at the:

1. air compressor outlet to the reservoir tank (Figure 7),
2. reservoir tank inlet (Figure 8),
3. reservoir tank outlet (Figure 9) to the bubbler ring.

Prior to impact pile driving, the compressor will be turned on and the valves will be open such that air will be supplied to the bubbler rings individually to visually confirm sufficient air to each ring. All valves will be opened during the operation of the bubble curtain. The bubble curtain will remain on during periods of active pile driving. The air pressure gauge will be used to monitor NAS operation during production pile driving. Air pressure at the outlet from the reservoir tank will be maintained at a target pressure of between 60 and 80 psi with a minimum pressure of 40 psi to each bubbler ring (Figure 10).

The following will be checked for each of the piles at each pier within Design Unit 7 (as outlined in the Construction Work Plan):

- Reservoir tank is pressurized prior to pile driving.
- The tank inlet and outlet valves are open immediately prior to pile driving.
- Air pressure at each reservoir tank outlet approximately 5 minutes after pile driving begins.
- Visual inspection of the water surface for sufficient air bubbles.

Figure 7. Valve at the Air Compressor Outlet to the Reservoir Tank

Figure 8. Valve at the Reservoir Tank Inlet

Figure 9. Valve at the Outlet from the Reservoir Tank to the Bubble Curtain

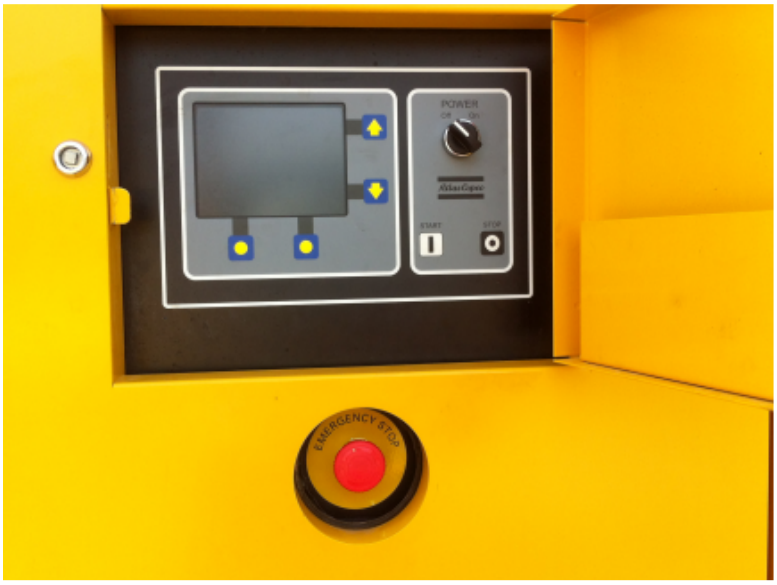

Figure 10. Air Compressor Controls

Attachment 1 – Daily Memoranda for Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile Installation

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 112L Installation

Daily Memorandum for 31 July 2013

Submitted to:
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25 February 2014

P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-112L is a 6-foot (ft) diameter pile driven at the construction site of the New NY Bridge on the east side of the navigation channel on 31 July 2013 (Table 1). Two real-time acoustic monitoring systems and three autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors, LLC (TZC) (Figure 1 and Table 2). Pile driving occurred between 17:57–18:57 Eastern Daylight Time (EDT), and full flood current occurred at 18:02 EDT.

Table 1. Summary of Test Pile PLT-112L activities, 31 July 2013.

Date:	31 July 2013
Pile-Driving Activity	
Test pile identifier:	PLT-112L
Pile diameter:	[redacted]
Water depth:	42 ft
Hammer type:	Impact (IHC S-800)
Total hammer strikes:	[redacted]
Total penetration:	[redacted]
Net duration of pile driving (hh:mm:ss):	00:04:27
Maximum single strike energy:	169 thousand foot-pounds (kip-ft), (229 kJ)
Total energy transferred:	28788 kip-ft (39.1 MJ)
Noise Attenuation System (NAS)	
Five-tier unconfined bubble curtain airflow rate:	900–2000 cubic feet minute (cfm), 35–80 pounds per square inch (psi)
River conditions during pile driving:	Flood current, 1–2 knots (0.5–1 meters per second [m/s] depth dependent; Table 6 and Figure 6)

Table 2 provides the sound levels measured at each recorder. Plots of the measured values, frequency distributions of 1/3-octave-band single-strike sound exposure levels (SELss), and sound level statistics for the distribution of the measured data are presented in Appendix A.

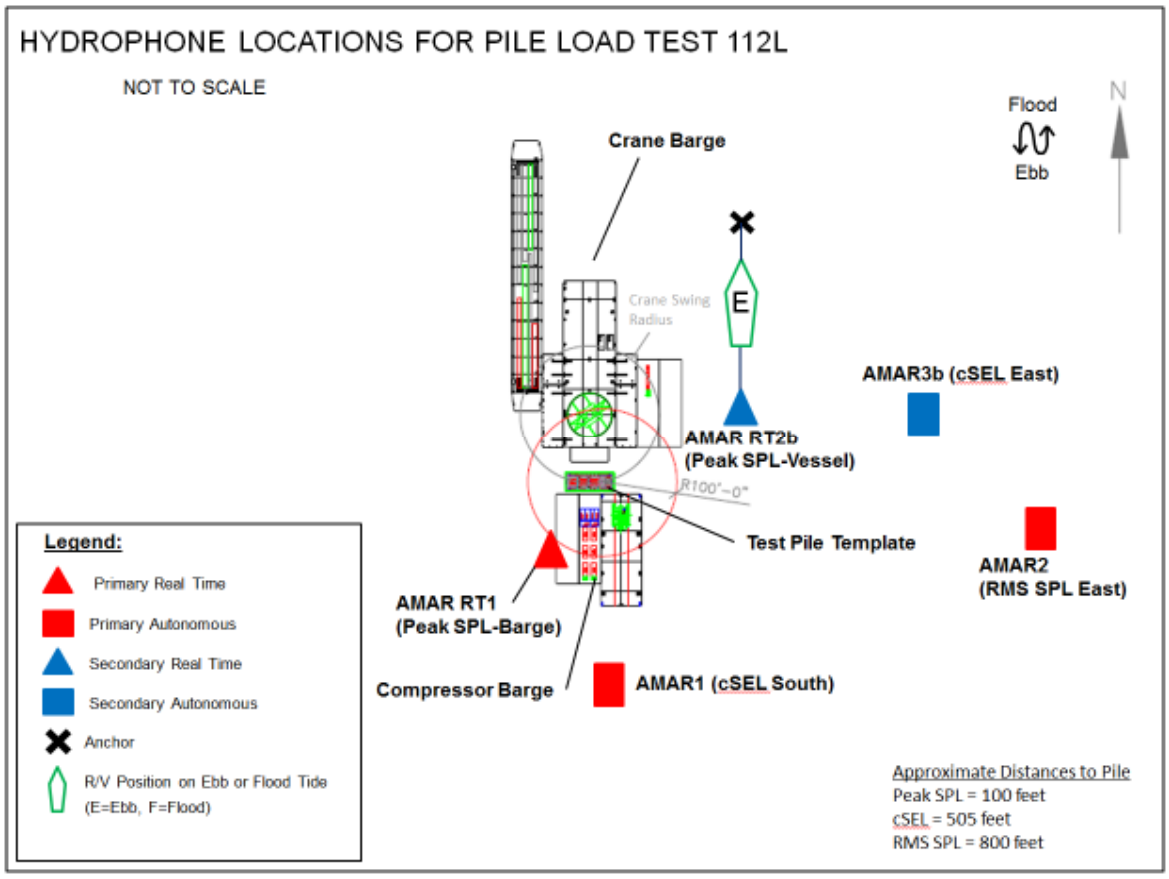

Figure 1. Plan view of pile and barge layout, 31 July 2013, PLT-112L.

Table 2. Summary of Autonomous Multichannel Acoustic Recorders (AMAR) locations and measured sound levels. Detailed sound level plots are contained in Appendix A.

Location	Recorder ID	Distance to pile (ft)	Water depth (ft)	Max peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^2·s*)
Peak SPL Barge (up current)	AMAR-RT-11	95	40	180	181
Peak SPL Vessel (cross current)	AMAR-RT-12	270	31	171	166
cSEL South (up current)	AMAR-221	556	41	169	170
cSEL East (cross current)	AMAR-222	598	20	164	160
rms SPL East (cross current)	AMAR-228	776	18	157	151

* Estimated at each recorder by multiplying the mean of the per-strike SEL by the number of strikes reported by the pile driving contractor, for the final value at the recorder, representing the total energy at the end of pile driving.

1.2. NMFS Physiological and Behavioral Thresholds

The distances from pile driving to the noise levels that serve as the National Marine Fisheries Service (NMFS) physiological and behavioral thresholds were extrapolated using a logarithmic regression based on mean values of the peak sound pressure level (SPL), root-mean-square (rms) SPL, and SELss from each recorder (Table 3 and Figure 2).

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was approximately 15 ft, and did not exceed NMFS criteria of a diameter of 100 ft for [redacted] piles. The diameter of the 187 dB re 1 $\mu Pa^2 \cdot s$ cumulative sound exposure level (cSEL) isopleth was estimated to be 110 ft at the end of pile driving. Since cSEL increases as the number of strikes increases, the diameter of the 187 dB isopleth was smaller than 110 ft for most of the pile driving operation. No other pile driving occurred during this pile load test. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

Table 3. Estimated isopleth diameters for the NMFS physiological and behavioral thresholds.

Criteria	Estimated diameter (ft)
206 dB re 1 µPa peak SPL	15
187 dB re 1 $\mu Pa^2 \cdot s$ cSEL*	110
150 dB re 1 µPa rms SPL (1 s integration time)	728

* At the end of pile driving

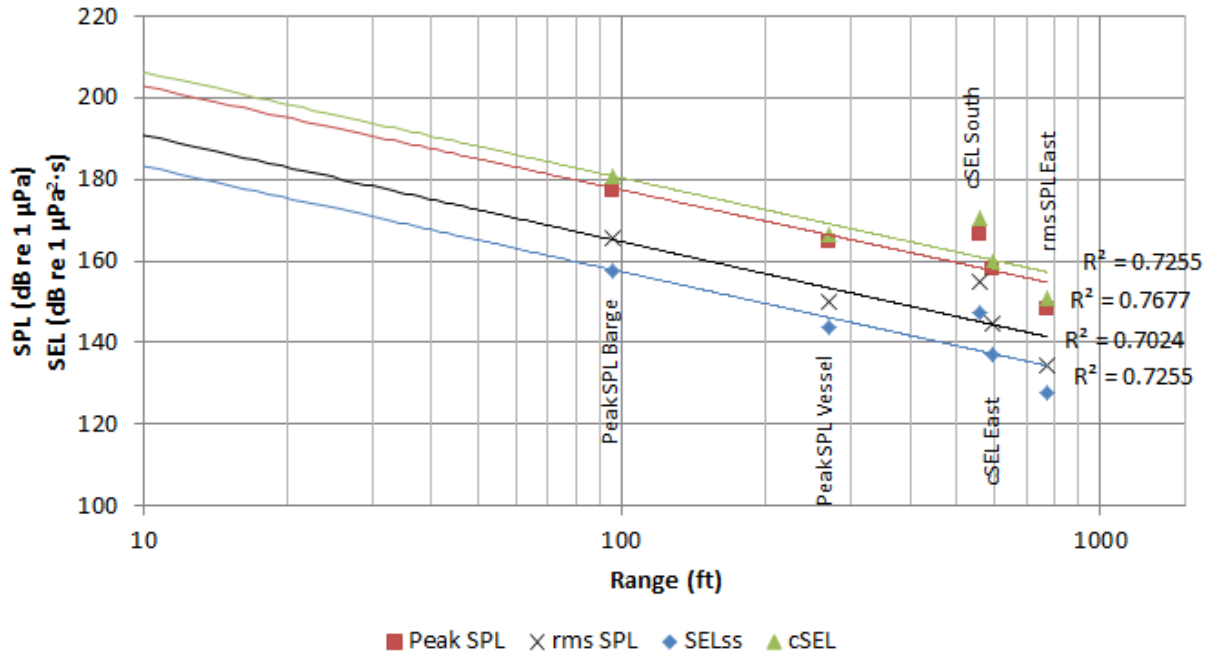

Figure 2. Regression based on mean values of the SELss, peak SPL, cSEL, and rms SPL from each recorder from pile driving of Test Pile PLT-112L, 31 July 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents total sound energy measured during the pile driving.

1.3. Observations

The impact hammer was operated at a hammer energy of 150 ± 15 kip-ft (Figure 3, Figure 4). The majority of the strikes at PLT-112L occurred between 17:57–18:06 (Figure 3, Figure 4) during full flood current (Figure 6). The ADCP measurements showed flood (northerly) currents of up to 2 knots (1 m/s) at depths of 4–18 ft. There were no observable changes in measured sound levels, with variation in air pressure The autonomous recorder at location cSEL South was directly upstream of the pile at a distance of 560 ft. It recorded sound levels that were higher than the autonomous recorder at location cSEL East, which was cross current from the pile driving at a range of 598 ft. The differences between the levels measured at locations cSEL South and cSEL East were (Figure 2, Figure 3, Figure 11, and Figure 13):

- rms SPL: 11 dB,
- peak SPL: 6 dB, and
- SELss: 11 dB.

The recorder at location cSEL South was 41 ft deep and location cSEL East was 20 ft deep. Two possible variables may explain the difference in sound levels,NAS performance variation due to orientation to the current and bathymetry. However, there is no indication that the required NMFS and NYSDEC thresholds were exceeded in any direction throughout installation of PLT 112L.

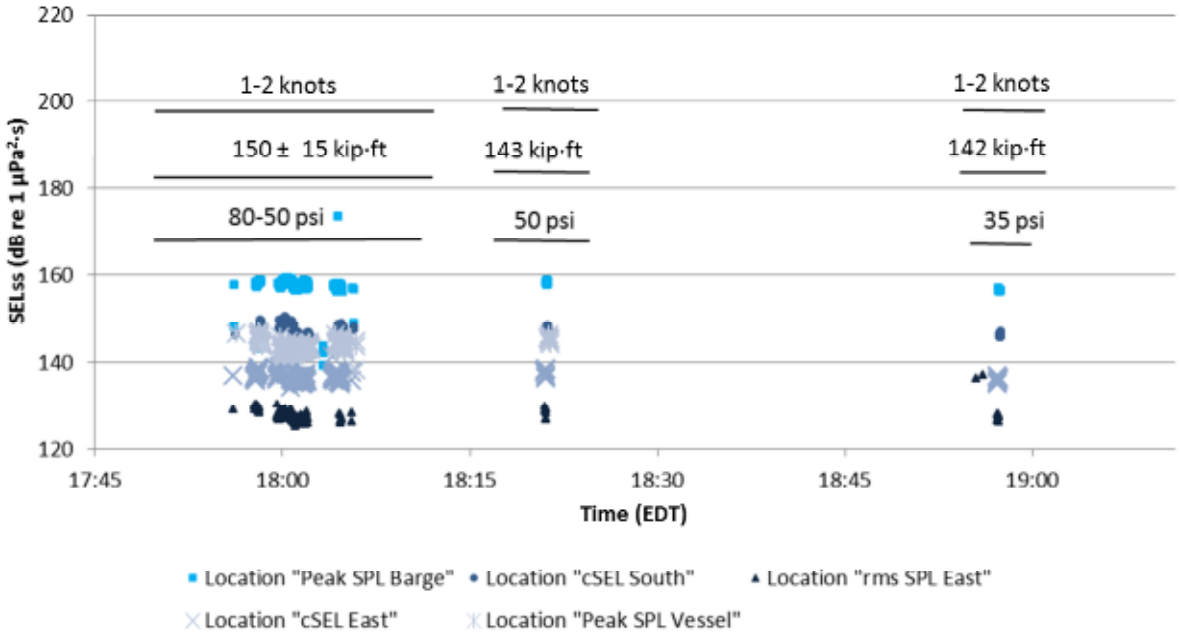

Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots)..

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 31 July 2013.

Table 4. JASCO and construction activities for Test Pile PLT-112L, 31 July 2013.

Time (EDT)	Activity
08:45	Safety meeting on shore
10:20	Transit to barge
10:25	Begin deploying AMARs
11:11	Complete all autonomous AMARs deployments
11:12	Stand by for impact hammering
14:13	Start vibratory hammering
15:30	Deploy AMAR-RT from Alpine vessel
16:10	Deploy AMAR-RT from barge
17:07	CTD cast from barge
17:56	Activate NAS
17:57	Start impact hammering
18:15	Stop main hammering
18:38	Begin retrieval of AMARs from Alpine vessel (ADCP shutdown)
18:57	Restrike pile 10 times; stop hammering
19:21	All AMARs retrieved
19:30	AMAR-RT retrieved
19:45	All work completed

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Five-tier unconfined bubble curtain

NAS settings: 900–2000 cfm, 35–80 psi

Table 5. NAS setting recorded during pile driving at Test Pile PLT-112L, 31 July 2013.

Time (EDT)	Volume/min (cfm)	Pressure (psi)
17:57	1800–2000	80
18:03	1200–1700	50
18:50	900–1100	35

2.2.2. Impact Hammering Log

Total energy: 28,788 kip-ft (39.1 MJ)

Total number of strikes: [redacted]

Maximum per-strike energy: 169 kip-ft (229 kJ)

Net pile driving duration (hh:mm:ss): 00:04:27

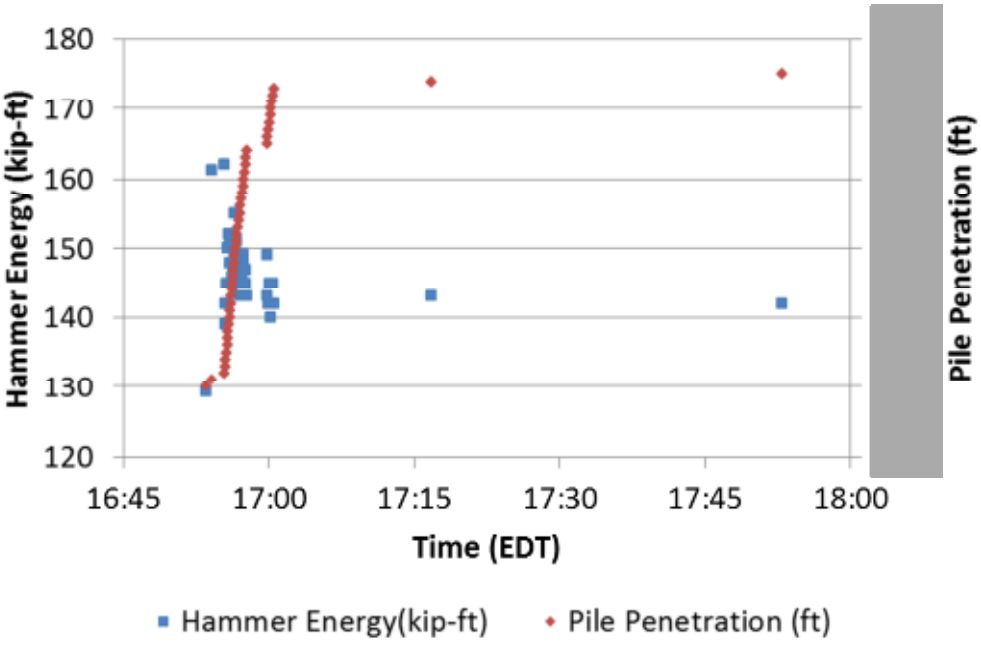

Figure 4. Hammer energy (kip-ft) and pile penetration (ft) for the impact pile driving of PLT-112L, 31 July 2013.

3. Weather and River Conditions

Table 6 provides the predicted currents at the project site for 31 July 2013. Figure 5 provides the measured speed of sound in water, based on a conductivity, temperature, depth (CTD) cast. Figure 6 provides the measured currents at the project site on 31 July using an Acoustic Doppler Current Profiler (ADCP).

Table 6. Weather conditions, current, and predicted local tide times (EDT).

Weather conditions:	Sunny, wind gusts to 5 mph
Full ebb current:	12:03 (1.6 knots)
Slack current:	14:47
Full flood current:	18:02 (1.1 knots)

Reference: http://tidesandcurrents.noaa.gov/get_predc.shtml?year=2013&stn=0611+George Washington Bridge&secstn=Tappan+Zee+Bridge&sbfh=%2B1&sbfm=12&fldh=%2B0&fldm=55&sbeh=%2B0&sbem=52&ebbh=%2B1&ebbm=06&fldr=0.6&ebbr=0.8&fldavgd=356&ebbavgd=175&footnote=

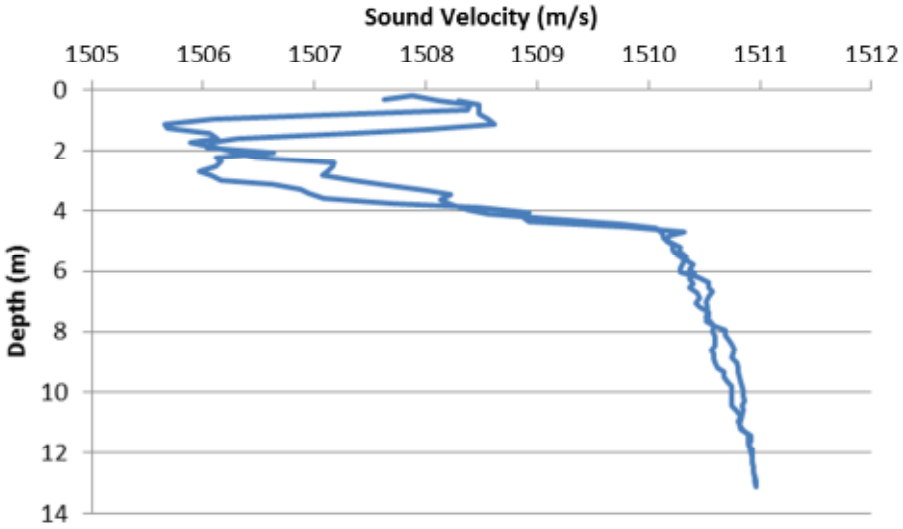

Figure 5. CTD cast performed at 17:07 (EDT) from the Alpine vessel, located 270ft East of PLT112L at Position Peak SPL Vessel (41.07148 N, 73.87743 W).

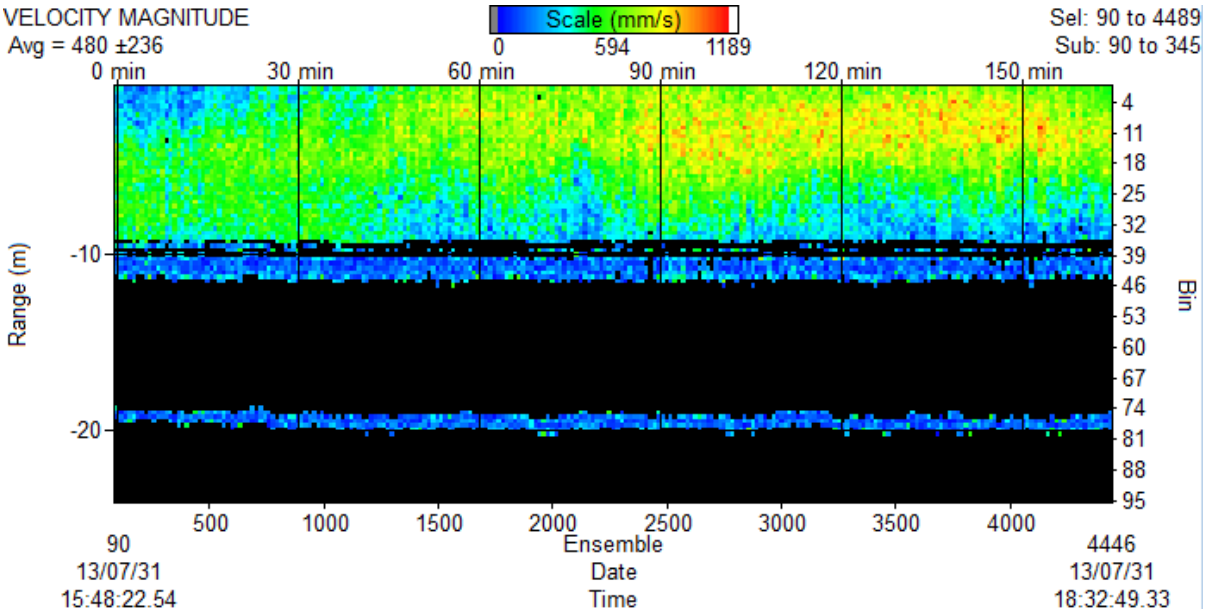

Figure 6. ADCP data from 31 July 2013 from the Alpine vessel, located 270ft East of PLT112L at Position Peak SPL Vessel (41.07148 N, 73.87743 W).Times are in EDT.

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 7 provides information on the real-time monitoring equipment used on 31 July 2013. Table 8 provides location information on the real-time recorder.

Table 7. Real-time monitoring equipment for Test Pile PLT-112L, 31 July 2013.

Equipment used		Units deployed
Acoustic data logger		
Model:	AMAR RT (JASCO Applied Sciences)	2
SpectroPlotter version:	6.0.1	2
Hydrophone		
Model:	M8KC (GTI)	2
AMAR-RT-11 sensitivity:	–211.3 dB re 1 V/µPa	1
AMAR-RT-12 sensitivity:	–210.8 dB re 1 V/µPa	1
Other		
Hydrophone calibrator:	Pistonphone Type 42ACPistonphone Type 42AC (G.R.A.S. Sound and Vibration)	1
CTD profiler:	Minos X (AML Oceanographic)	1
ADCP:	RDI Teledyne Workhorse Sentinel 1200 kHz	1

Table 8. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 31 July 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
Peak SPL Barge (up current)	AMAR-RT-11	41.07126	73.87862	16:10	40	95
Peak SPL Vessel (cross current)	AMAR-RT-12	41.07148	73.87743	15:30	31	270

4.2. Autonomous Monitoring Equipment

Table 9 provides information about the autonomous monitoring equipment used on 31 July 2013. Table 10 provides the locations of the autonomous recorders.

Table 9. Autonomous monitoring equipment for Test Pile PLT112L, 31 July 2013.

Equipment used		Units deployed
Acoustic data logger		
Model:	AMAR G3 (JASCO Applied Sciences)	3
SpectroPlotter version:	6.0.1	3
Hydrophone		
Model:	M8E-51-0dB (GTI)	3
AMAR-221 sensitivity:	–199.8 dB re 1 V/µPa	1
AMAR-222 sensitivity:	–199.9 dB re 1 V/µPa	1
AMAR-228 sensitivity:	–199.5 dB re 1 V/µPa	1

Table 10. Locations (WGS84) and deployment times (EDT) of the Autonomous AMAR monitoring stations on 31 July 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
rms SPL East (cross current)	AMAR-228	41.07072	73.8756	11:05	18	776
cSEL East (cross current)	AMAR-222	41.0710	73.8763	10:57	20	598
cSEL South (up current)	AMAR-221	41.06986	73.8782	10:49	41	556

Appendix A. Pile Driving Plots

A.1. Impact Pile-Driving Sound Levels from Peak SPL Barge

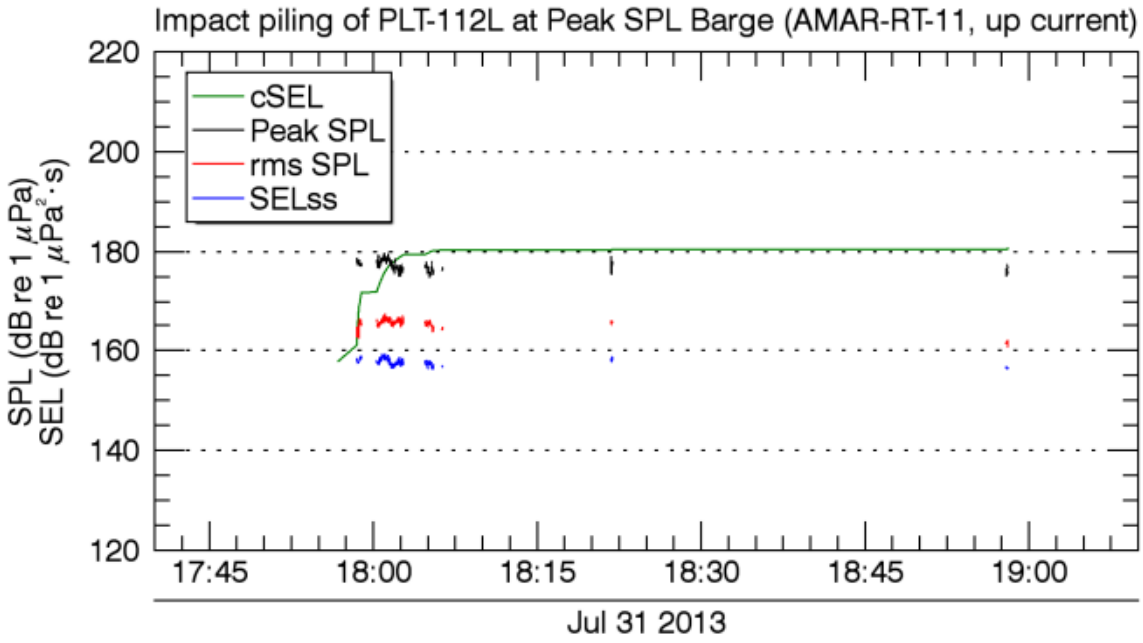

Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 95 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

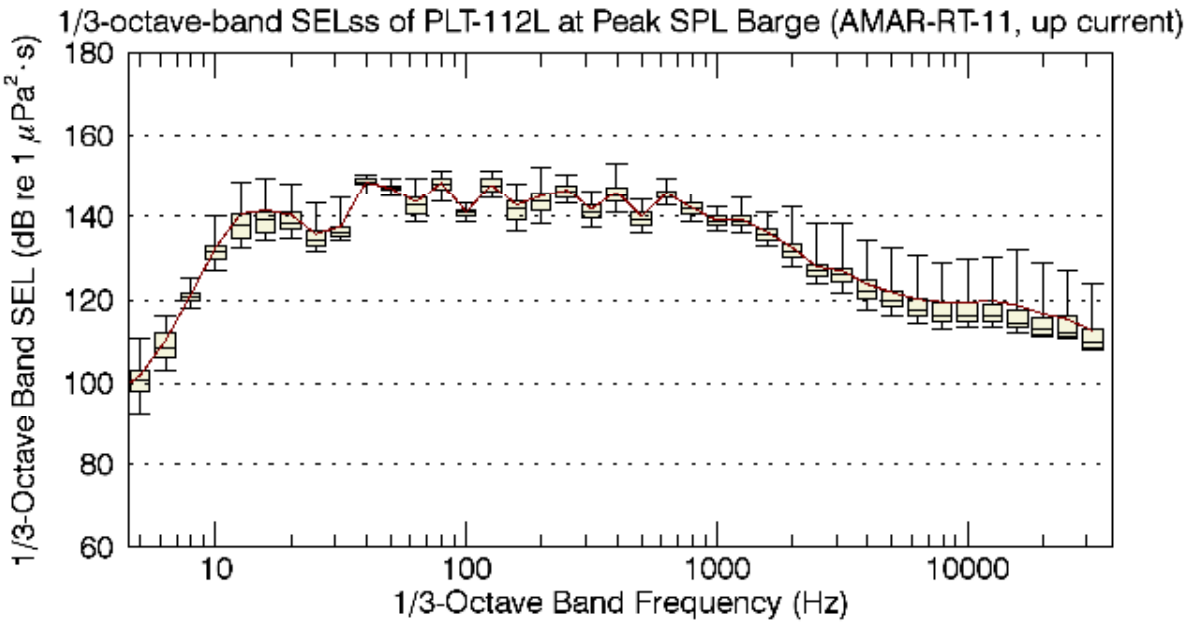

Figure 8. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112L measured 95 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 11. Sound levels for the pile driving of Test Pile PLT-112L measured 95 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	179.8	167.2	159.2
L_5	179.0	166.6	158.8
L_{25}	178.1	165.9	158.1
L_{50}	177.3	165.5	157.6
L_{75}	176.6	165.0	157.1
L_{95}	175.5	162.5	156.4
L_{mean}	177.4	165.4	157.7

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.2. Impact Pile-Driving Sound Levels from Peak SPL Vessel

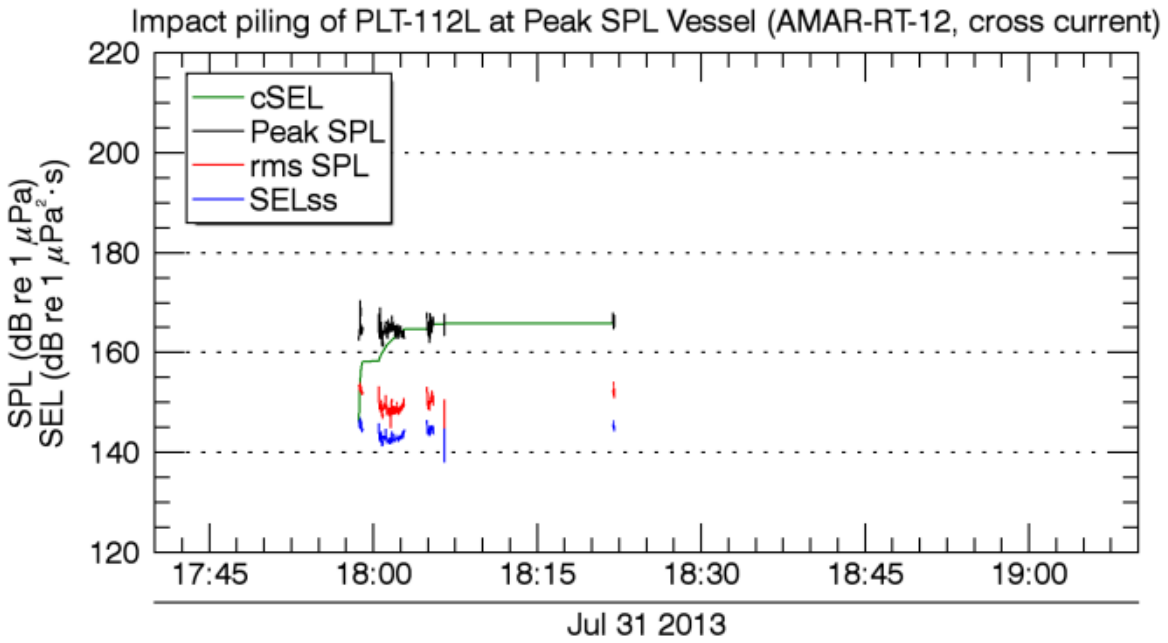

Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 270 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time. AMAR-RT-12 was retrieved before the pile driving at 18:57 occurred.

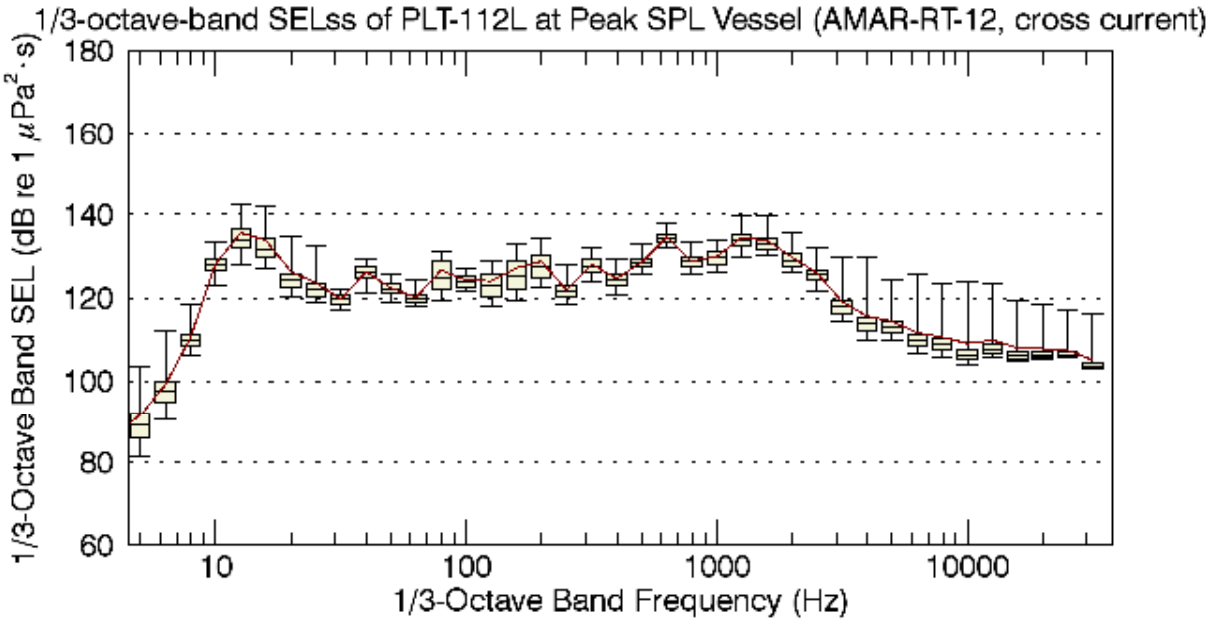

Figure 10. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112L measured 270 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 12. Sound levels for the pile driving of Test Pile PLT-112L measured 270 ft from the pile at location Peak SPL Vessel using AMAR-RT-12.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	170.5	154.1	147.0
L_5	167.2	153.1	146.1
L_{25}	165.4	150.4	144.3
L_{50}	164.3	149.2	143.2
L_{75}	163.6	148.3	142.6
L_{95}	162.5	147.4	141.9
L_{mean}	164.8	149.9	143.6

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.3. Impact Pile-Driving Sound Levels cSEL South

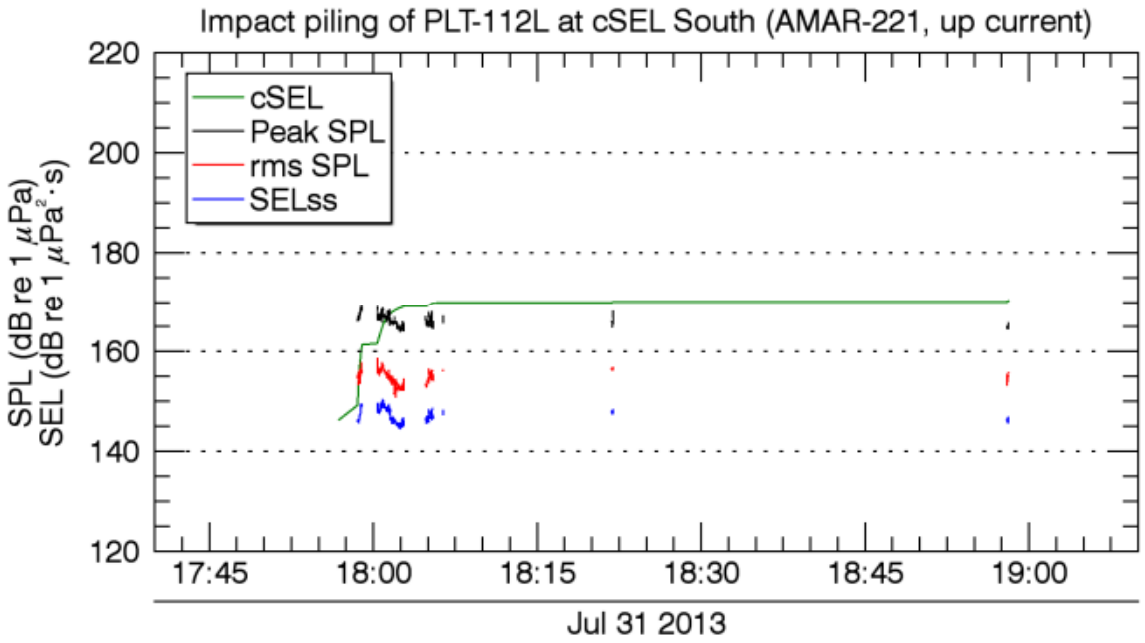

Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 556 ft from the pile at location cSEL South using AMAR-221. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

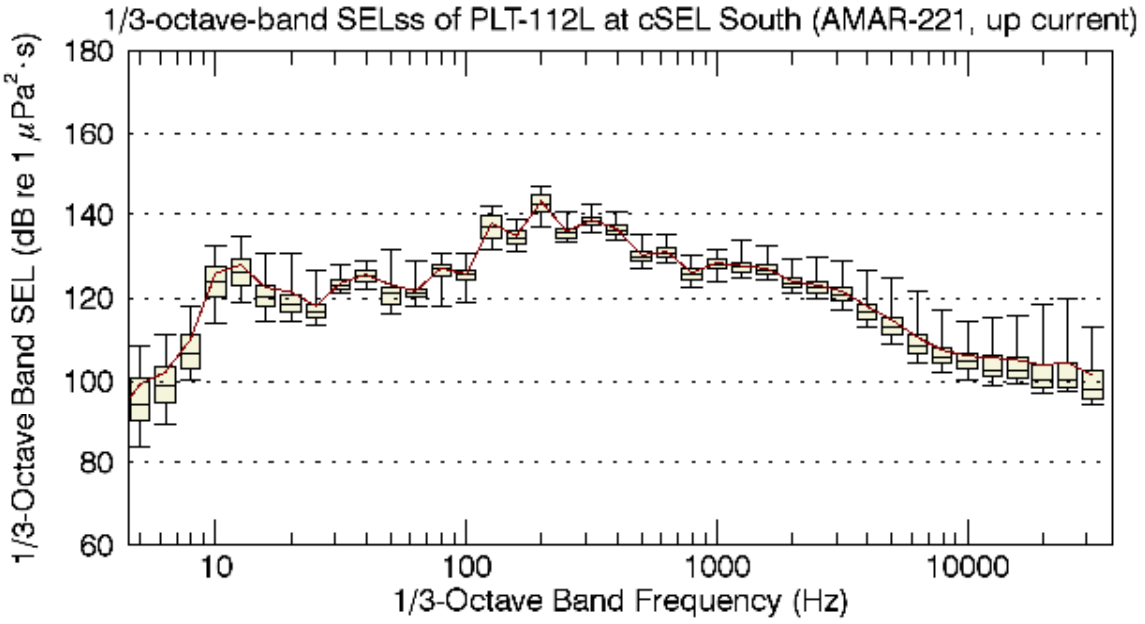

Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112L measured 556 ft from the pile at location cSEL South using AMAR-221. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 13. Sound levels for the pile driving of Test Pile PLT-112L measured 556 ft from the pile at location cSEL South using AMAR-221.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	169.1	158.5	150.4
L_5	168.4	156.7	149.6
L_{25}	166.8	155.9	148.2
L_{50}	166.0	155.0	147.0
L_{75}	165.3	153.5	146.0
L_{95}	164.5	152.3	145.2
L_{mean}	166.3	155.0	147.4

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.4. Impact Pile-Driving Sound Levels cSEL East

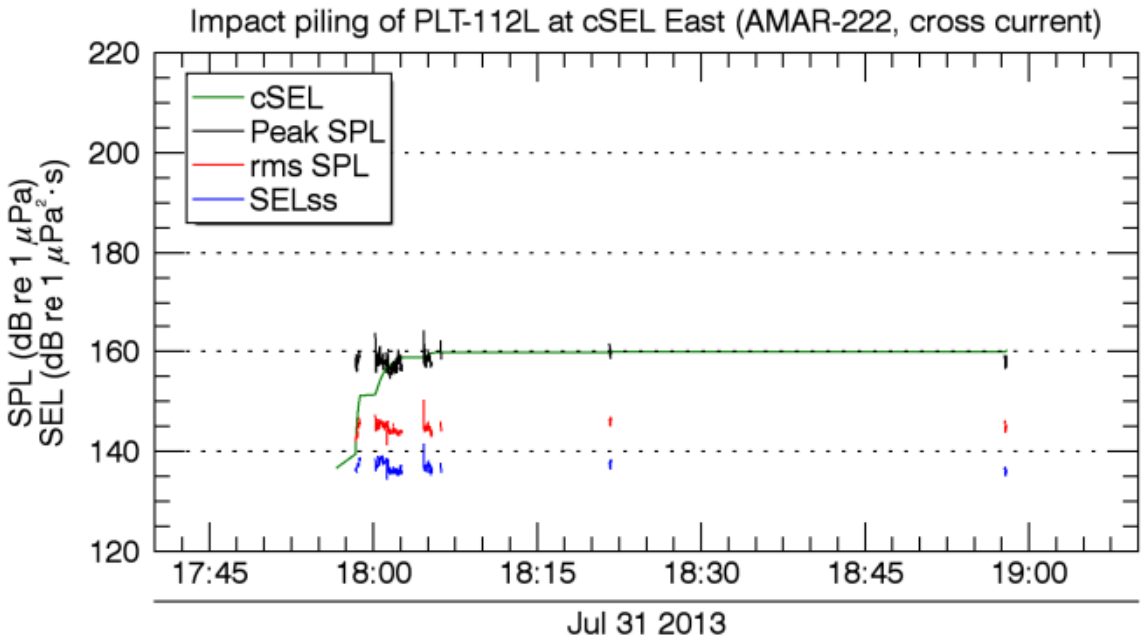

Figure 13. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 598 ft from the pile at location cSEL East using AMAR-222. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

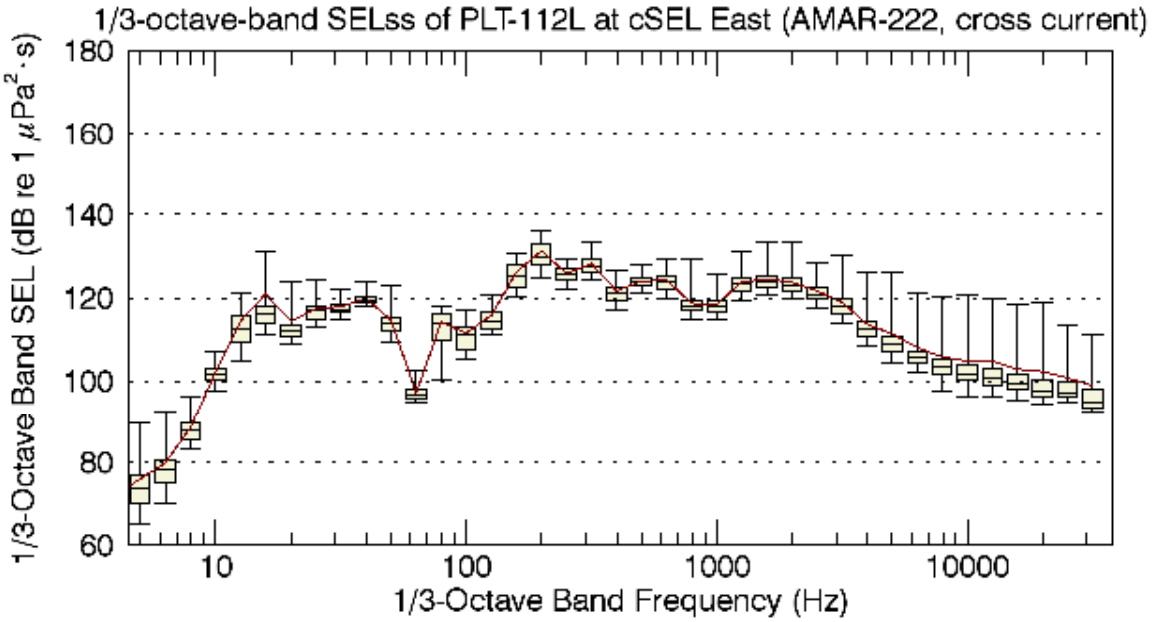

Figure 14. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112L measured 598 ft from the pile at location cSEL East using AMAR-222. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 14. Sound levels for the pile driving of Test Pile PLT-112L measured 598 ft from the pile at location cSEL East using AMAR-222.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	164.0	150.1	141.4
L_5	160.3	146.2	138.7
L_{25}	158.6	145.3	137.6
L_{50}	157.8	144.6	136.7
L_{75}	156.9	143.9	136.0
L_{95}	155.7	142.9	135.3
L_{mean}	158.1	144.7	137.0

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.5. Impact Pile-Driving Sound Levels rms SPL East

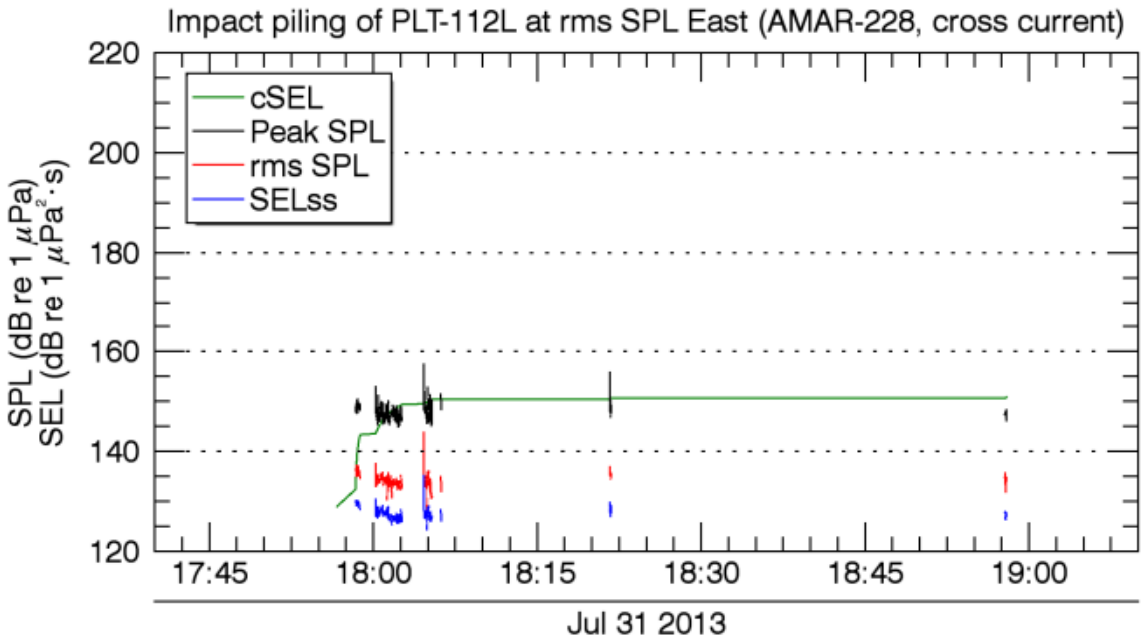

Figure 15. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 776 ft from the pile at location rms SPL East using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

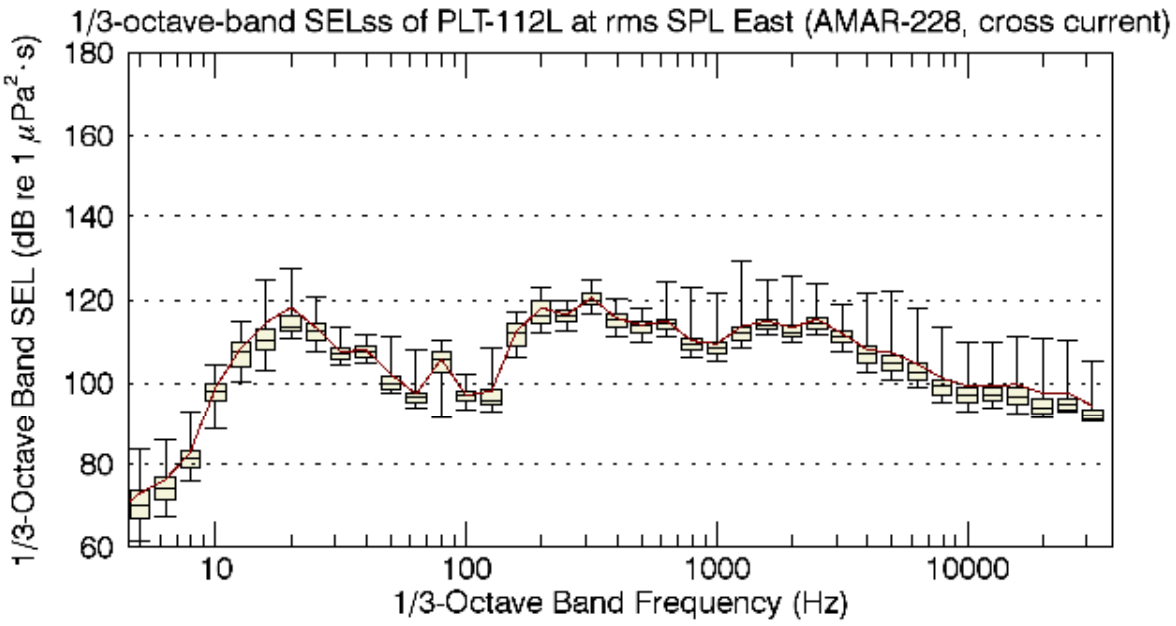

Figure 16. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112L measured 776 ft from the pile at location rms SPL East using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 15. Sound levels for the pile driving of Test Pile PLT-112L measured 776 ft from the pile at location rms SPL East using AMAR-228.Sound levels for the measurements at location rms SPL East during pile driving of PLT-112L (776 ft from pile PLT-112L, AMAR-228).

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa²·s)
L_{max}	157.3	143.8	135.1
L_5	150.6	136.2	129.8
L_{25}	148.9	134.9	128.3
L_{50}	147.7	134.2	127.3
L_{75}	146.7	133.4	126.8
L_{95}	145.6	131.8	125.9
L_{mean}	148.4	134.5	127.8

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 112 Installation

Daily Memorandum for 03 August 2013

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25 February 2014

P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-112 is a [redacted] pile driven at the construction site of the New NY Bridge on the east side of the navigation channel on 03 August 2013 (Table 1). Two real-time acoustic monitoring systems and three autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors LLC (TZC) (Figure 1 and Table 2). Pile driving occurred between 14:00–16:20 EDT, and full ebb current occurred at 14:53 EDT.

Table 2 provides the sound levels measured at each recorder. Plots of the measured values, frequency distributions of 1/3-octave-band single-strike sound exposure levels (SELss), and sound level statistics for the distribution of the measured data are presented in Appendix A.

Table 1. Summary of PLT-112 activities, 03 August 2013.

Date:	03 August 2013
Pile-driving activity	
Test pile identifier:	PLT-112
Pile diameter:	[redacted]
Water depth:	42 ft
Hammer type:	Impact (IHC S-800)
Total hammer strikes:	[redacted]
Total penetration:	[redacted]
Net duration of pile driving (hh:mm:ss):	00:26:00
Maximum single strike energy:	569 thousand foot-pounds (kip-ft), (776 kJ)
Total energy transferred:	271,310 kip-ft (390 MJ)
Noise Attenuation System (NAS)	
Five-tier unconfined bubble curtain airflow rate:	900–2000 cubic feet per minute (cfm), 40–70 pounds per square inch (psi)
River conditions during pile driving:	Ebb current, 0.6–2 knots (0.3–1 meters per second [m/s] depth dependent; Table 8 and Figure 6)

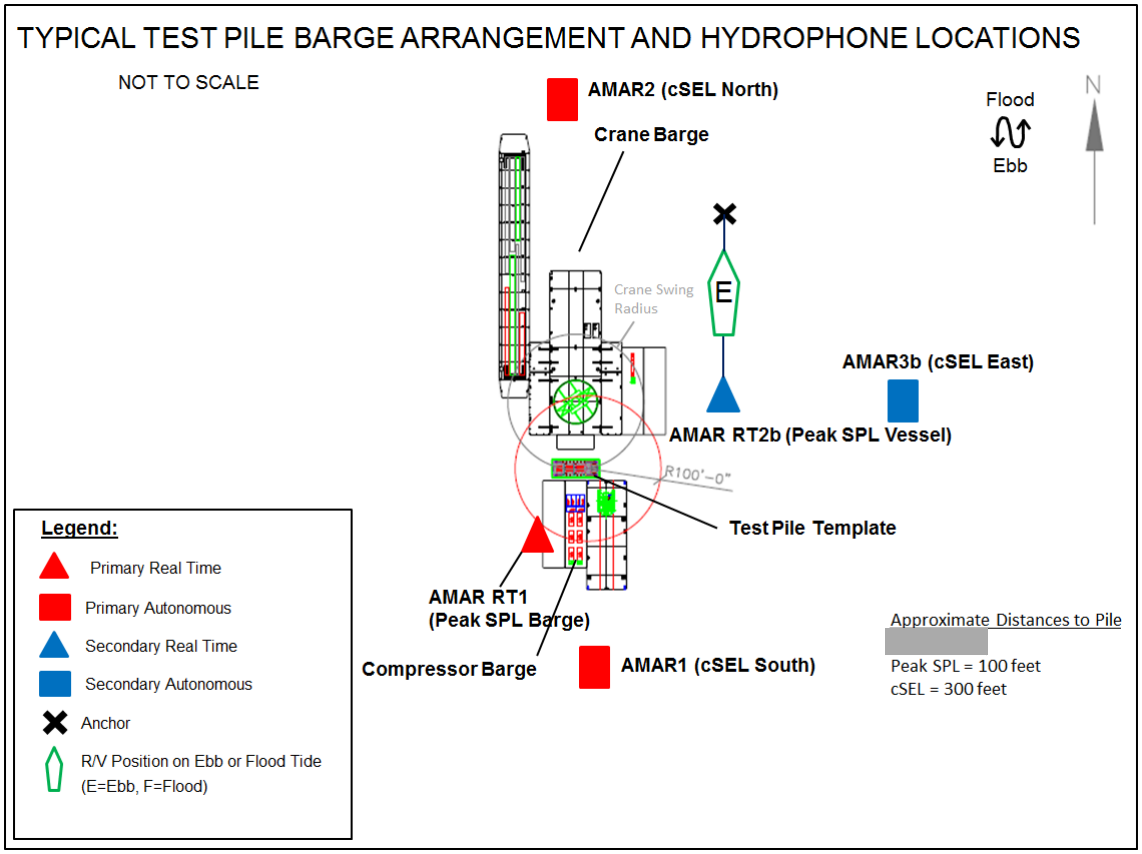

Figure 1. Plan view of pile and barge layout, 03 August 2013, PLT-112.

Table 2. Summary of Autonomous Multichannel Acoustic Recorder (AMAR) locations and measured sound levels. Detailed sound level plots are contained in Appendix A.

Location	Recorder ID	Distance to pile (ft)	Water depth (ft)	Max peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^{2}s)*
Peak SPL Barge (down current)	AMAR-RT-11	100	40	182	185
Peak SPL Vessel (cross current)	AMAR-RT-12	170	34	180	179
cSEL East (cross current)	AMAR-221	282	31	179	176
cSEL North (up current)	AMAR-222	365	36	180	175
cSEL South (down current)	AMAR-228	238	40	175	177

* Estimated at each recorder by multiplying the mean of the per-strike SEL by the number of strikes reported by the pile driving contractor, for the final value at the recorder, representing the total energy at the end of pile driving.

1.2. NMFS Physiological and Behavioral Thresholds

The distances from pile driving to the noise levels that serve as the National Marine Fisheries Service (NMFS) physiological and behavioral thresholds were extrapolated using a logarithmic regression based on mean values of the peak sound pressure levels (SPL), root mean square (rms) SPL, and SELss from each recorder (Table 3 and Figure 2).

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was less than 6 ft, and did not exceed NMFS criteria of a diameter of 100 ft for [redacted] piles. The diameter of the 187 dB re 1 $\mu Pa^2 \cdot s$ cumulative sound exposure level (cSEL) isopleth was estimated to be 190 ft at the end of pile driving. Since cSEL increases as the number of strikes increases, the diameter of the 187 dB isopleth was smaller than 190 ft for most of the pile driving operation. No other pile driving occurred during this pile load test. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

Table 3. Estimated isopleth diameters for the NMFS physiological and behavioral thresholds.

Criteria	Estimated mean diameters (ft)
206 dB re 1 µPa peak SPL	< 6
187 dB re 1 $\mu Pa^2 \cdot s$ cSEL*	190
150 dB re 1 µPa rms SPL (1 s integration time)	924

* At the end of pile driving

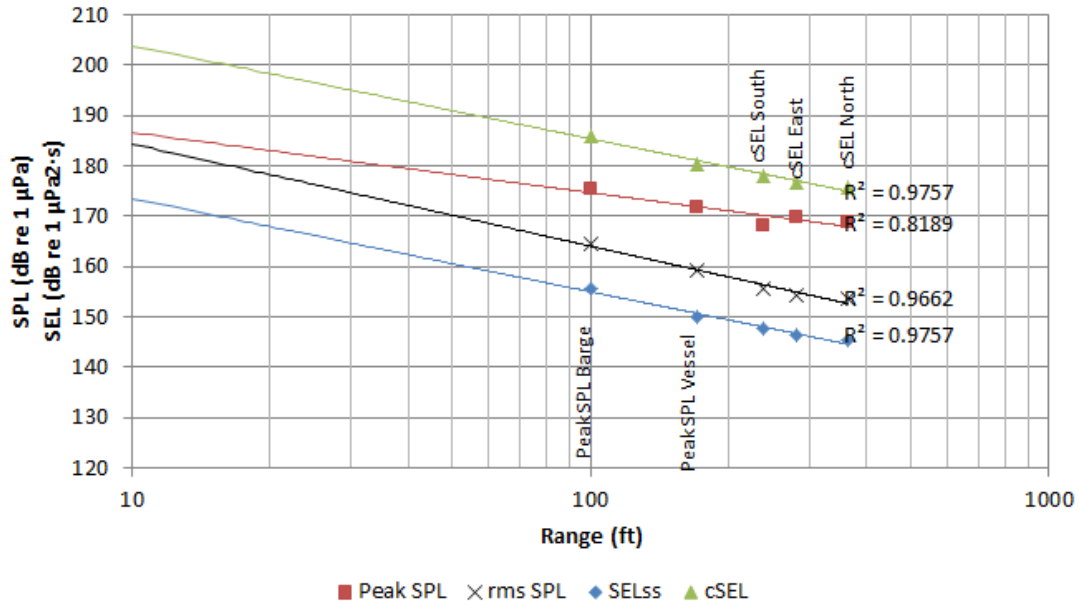

Figure 2. Regression based on mean values of the SELss, peak SPL, cSEL, and rms SPL from each recorder from pile driving of PLT-112, 03 August 2013. SELss, Peak SPL, and rms SPL are instantaneous values. The cSEL represents total sound energy measured during the pile driving.

1.3. Observations

The hammer energy during pile driving at PLT-112 was 100-150 kip-ft for approximately 2/3 of the pile driving, and increased to 210 kip-ft and then 300-500 kip-ft at the end of pile driving (Figure 3, Figure 4). The NAS air pressure and airflow were 70 psi and 1700–2000 cfm while the hammer energy was 100-150 kip-ft (Figure 3, Table 7). NAS air pressure was reduced to 50 psi while the hammer energy was 210 kip-ft, and to 40 psi while the hammer energy was 300-500 kip-ft (Figure 3, Table 7). The majority of the pile driving occurred during the ebb current, with an approximate average current of 1.5 knots, with the exception of the strikes around 12:35 when the average current was approximately 0.8 knots (Figure 3, Figure 6).

Sound levels appear to be negatively correlated with the NAS air flow (measured sound levels increase as air flow decreases) or positively correlated with the hammer energy (Figure 3, Table 4). Differences in measured sound levels as a function of NAS settings and hammer energy were found by subtracting the sound levels from the 70 psi measurements from the levels on the same recorder at the other NAS settings (Table 4). For example, peak SPL at location cSEL North was 163 dB at 70 psi and 171 dB at 40 psi, for a difference of 8 dB. There is a 5–9 dB difference in the peak SPL, 4–6 dB difference in the rms SPL, and 4–6 dB difference in the SELss at each recorder among the three NAS settings and hammer energy states (Table 4). The sound levels were higher when the NAS setting was lower; however, hammer energy and river current were higher during the measurements with lower NAS air flow. The distances to each NMFS threshold meet the NMFS and NYSDEC permit thresholds in all measurements states (Table 5).

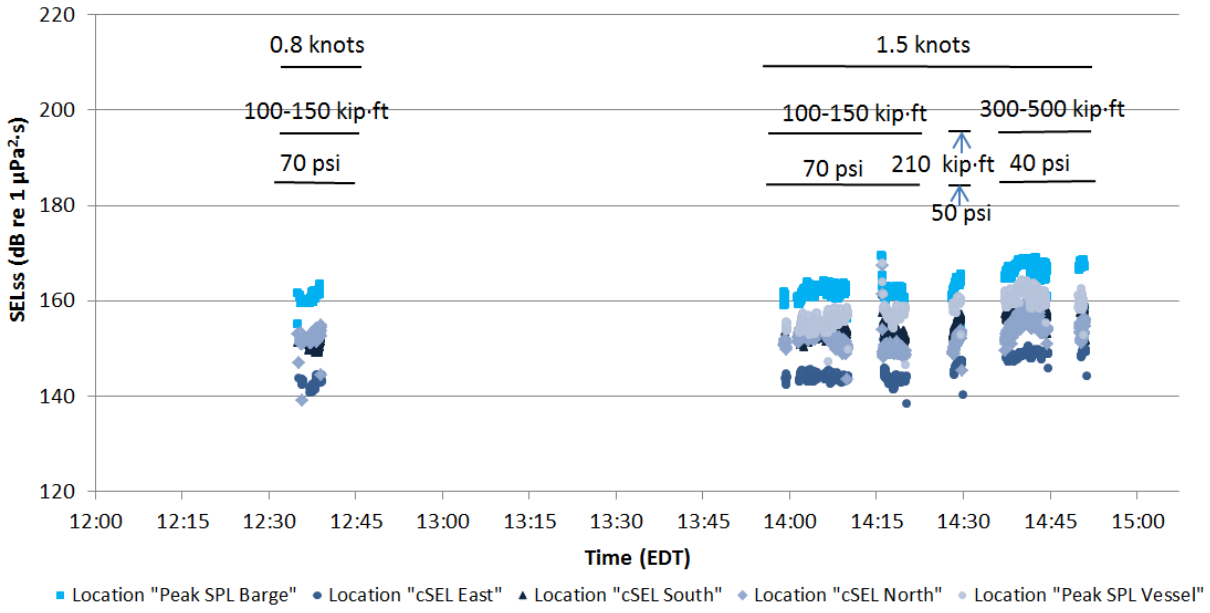

Figure 3. Measured sound levels versus time (EDT), hammer energy, NAS pressure settings, and river current (knots). The measurements were made at location Peak SPL Barge, 100 ft down current from the pile.

Table 4. Median sound levels measured during each NAS air flow setting during installation of Test Pile PLT-112, 03 August 2013.

Location	Distance to pile (ft)	70 psi, 100–150 kip-ft			50 psi, 210 kip-ft			40 psi, 300–500 kip-ft		
		Peak SPL[1]	rms SPL[1]	SELss[2]	Peak SPL[1]	rms SPL[1]	SELss[2]	Peak SPL[1]	rms SPL[1]	SELss[2]
Peak SPL Barge	100	172	162	153	174	163	155	177	167	158
Peak SPL Vessel	170	168	156	147	171	159	150	174	161	152
cSEL East	282	164	151	143	168	154	146	173	156	148
cSEL North	365	163	151	142	164	151	143	171	155	147
cSEL South	238	164	152	144	166	155	147	170	158	150

[1] dB re 1 µPa.
[2] dB re 1 µPa^2·s.
Effects of changing settings are found by subtracting the sound levels from the 70 psi measurements from the levels on the same recorder at the other settings. For example, the peak SPL at location cSEL North was 163 dB at 70 psi and 171 dB at 40 psi, for a difference of 8 dB.

Table 5. Estimated isopleth diameters for the NMFS physiological and behavioral thresholds as a function of NAS air pressure.

Criteria	Estimated diameters (ft)		
	70 psi 100–150 kip-ft	50 psi 210 kip-ft	40 psi 300–500 kip-ft
206 dB re 1 µPa peak SPL	< 6	< 6	< 6
187 dB re 1 µPa^2·s cSEL*	116	160	224
150 dB re 1 µPa rms SPL (1 s integration time)	774	882	1220

* At the end of pile driving assuming 1089 strikes

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 6 provides activities for 03August 2013.

Table 6. JASCO and construction activities for Test Pile PLT-112, 03August 2013.

Time (EDT)	Activity
10:05	Safety meeting on shore
10:13	Perform hydrophone calibration on AMAR-RT
10:20	Transit to barge
10:25	Begin deploying AMARs

11:00	Complete all autonomous AMARs deployments
12:20	Deploy AMAR-RT from barge
12:30	Deploy AMAR-RT from vessel
12:35	Preliminary strikes, stopped after two strikes to install stress-test equipment
14:00	Start impact pile driving
15:07	Move barge back 5 ft
15:38	Lift and redeploy AMAR-RT on barge
15:56	CTD cast from barge
16:17	Stop impact hammering
18:00	Begin retrieval of AMARs from Alpine vessel (shutdown ADCP)
18:38	All AMARs retrieved
18:58	Alpine vessel at dock
19:30	All work completed

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Five-tier unconfined bubble curtain

NAS settings: 900-2000 cfm, 40-70 psi

Table 7. NAS setting recorded during pile driving at Test Pile PLT-112, 03 August 2013.

Time (EDT)	Volume/min (cfm)	Pressure (psi)
14:03	1700–2000	70
14:18	1200–1300	50
14:30	900–1100	40

2.2.2. Impact Hammering Log

Total energy: 271,310 kip-ft (390 MJ)

Total number of strikes: [redacted]

Maximum per-strike energy: 569 kip-ft (776 kJ)

Net pile driving duration (hh:mm:ss): 00:26:00

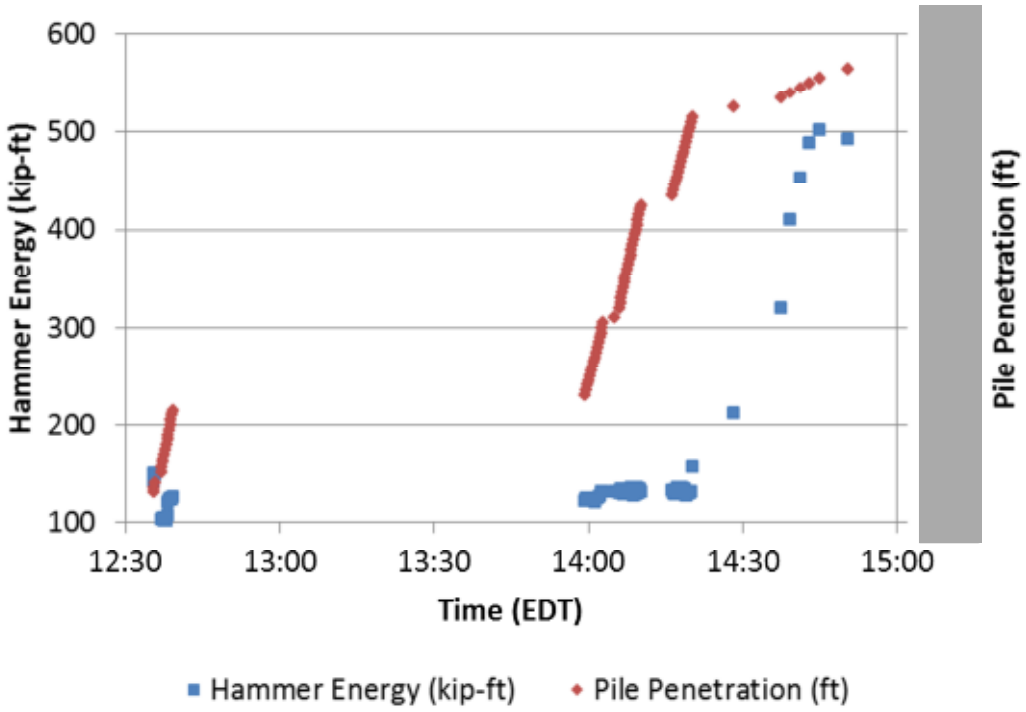

Figure 4.Hammer energy (kip-ft) and pile penetration (ft) for the impact pile driving of PLT-112, 03 August 2013.

3. Weather and River Conditions

Table 8 provides the predicted currents at the project site on 03 August 2013. Figure 5 provides the measured speed of sound in water, based a conductivity, temperature, depth (CTD) cast. Figure 6 provides the measured currents at the project site on 03 August using an Acoustic Doppler Current Profiler (ADCP).

Table 8. Weather conditions, current, predicted local tide times (EDT), and water depth.

Weather conditions:	Clouds, rain, wind SW 5 knots building to 15–20 knots
Full ebb current:	14:27 (1.6 knots)
Slack current:	10:45, 17:06
Full flood current:	N/A

Reference: http://tidesandcurrents.noaa.gov/get_predc.shtml?year=2013&stn=0611+George Washington Bridge&secstn=Tappan+Zee+Bridge&sbfh=%2B1&sbfm=12&fldh=%2B0&fldm=55&sbeh=%2B0&sbem=52&ebbh=%2B1&ebbm=06&fldr=0.6&ebbr=0.8&fldavgd=356&ebbavgd=175&footnote=

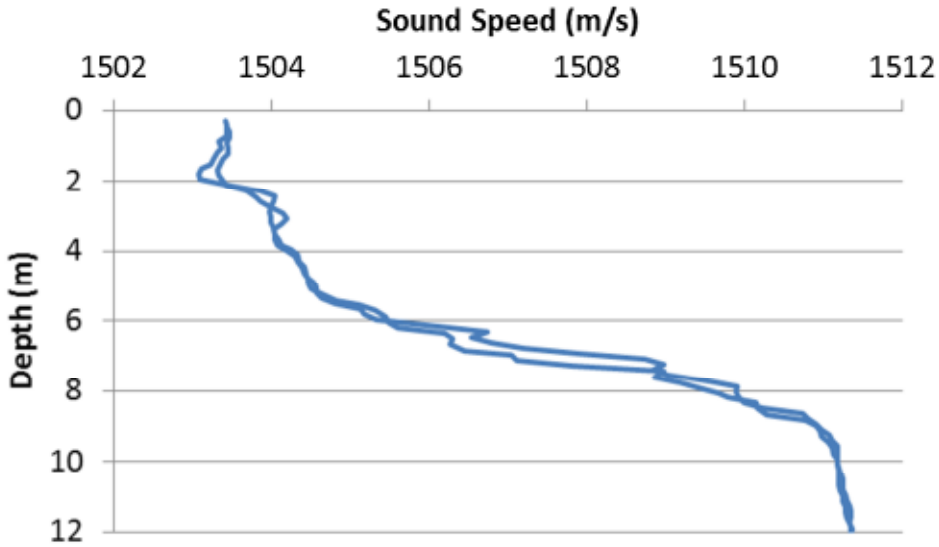

Figure 5. CTD Cast performed at 15:56 (EDT) from the Alpine vessel, located 170ft East of the PLT112 at position Peak SPL Vessel (41.07130 N, 73.8779 W).

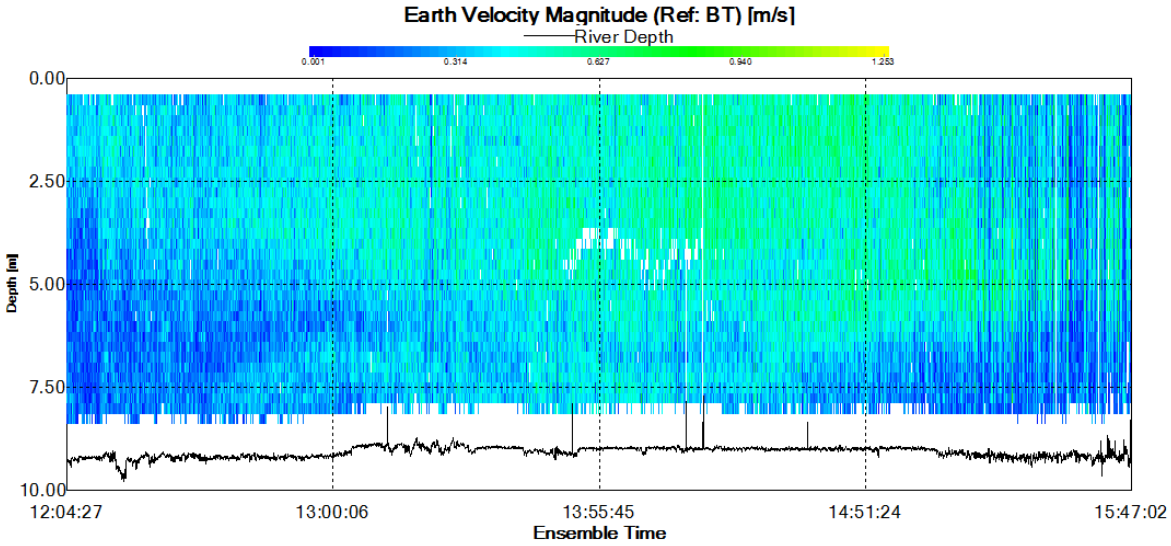

Figure 6. ADCP data from 03 August 2013 from the Alpine vessel, located 170ft East of PLT112 at position Peak SPL Vessel (41.07130 N, 73.8779 W).

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 9 provides information on the real-time monitoring equipment used on 03 August 2013. Table 10 provides location information on the real-time recorders.

Table 9. Real-time monitoring equipment for Test Pile PLT-112, 03 August 2013.

Equipment used		Units deployed
Acoustic data logger		
Model:	AMAR RT (JASCO Applied Sciences)	2
SpectroPlotter version:	6.0.1	2
Hydrophone		
Model:	M8KC (GTI)	2
AMAR-RT-11 sensitivity:	−210.8 dB re 1 V/µPa	1
AMAR-RT-12 sensitivity:	−210.9 dB re 1 V/µPa	1
Other		
Hydrophone calibrator:	42AC Pistonphone calibrator (G.R.A.S. Sound and Vibration)	1
CTD profiler:	Minos X (AML Oceanographic)	1
ADCP:	RDI Teledyne Workhorse Sentinel 1200 kHz	1

Table 10. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 03 August 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
Peak SPL Barge (down current)	AMAR-RT-11	41.07114	−73.8787	12:22	40	100
Peak SPL Vessel (cross current)	AMAR-RT-12	41.07130	−73.8779	12:30	34	170

4.2. Autonomous Monitoring Equipment

Table 11 provides information about the autonomous monitoring equipment used on 03 August 2013. Table 12 provides the locations of the autonomous recorders.

Table 11. Autonomous monitoring equipment for Test Pile PLT-112, 03 August 2013.

Equipment used		Units deployed
Acoustic data logger		
Model:	AMAR G3 (JASCO Applied Sciences)	3
SpectroPlotter version:	6.0.1	3
Hydrophone		
Model:	M8E-51-0dB (GTI)	3
AMAR-221 sensitivity:	−199.7 dB re 1 V/µPa	1
AMAR-222 sensitivity:	−199.8 dB re 1 V/µPa	1
AMAR-228 sensitivity:	−199.6 dB re 1 V/µPa	1

Table 12. Locations (WGS84) and deployment times (EDT) of the autonomous AMAR monitoring stations, 03 August 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
cSEL East (cross current)	AMAR-221	41.07139	−73.87748	10:53	31	282
cSEL North (up current)	AMAR-222	41.07239	−73.8785	10:44	36	365
cSEL South (down current)	AMAR-228	41.0707	−73.8784	10:48	40	238

Appendix A. Pile Driving Plots

A.1. Impact Pile-Driving Sound Levels from Peak SPL Barge

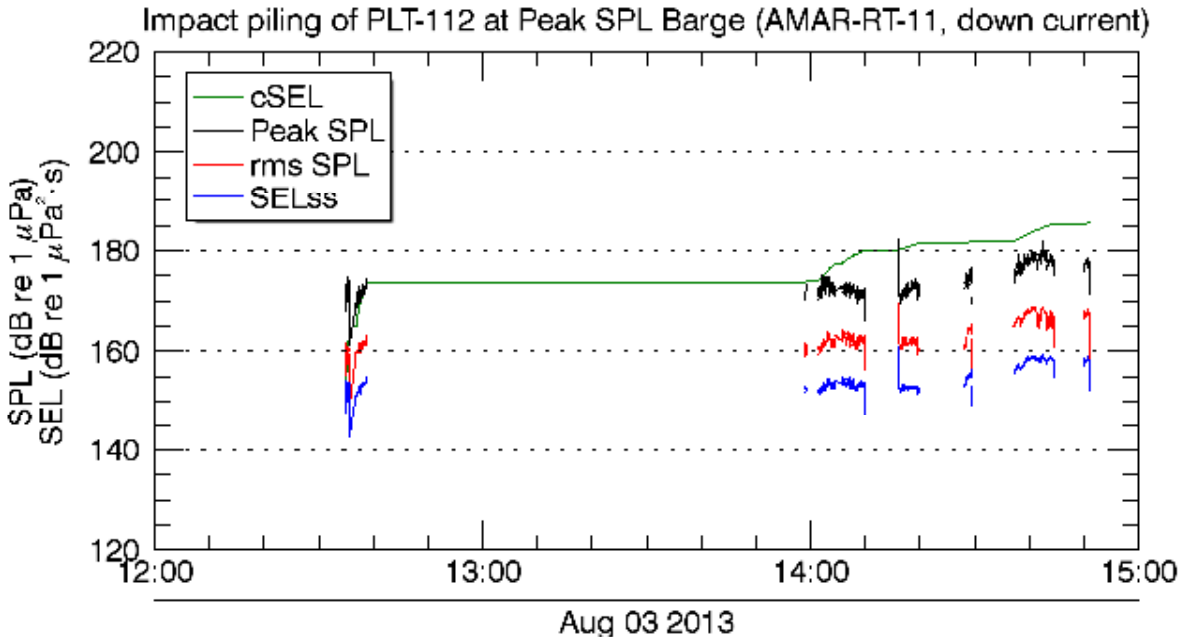

Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 100 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

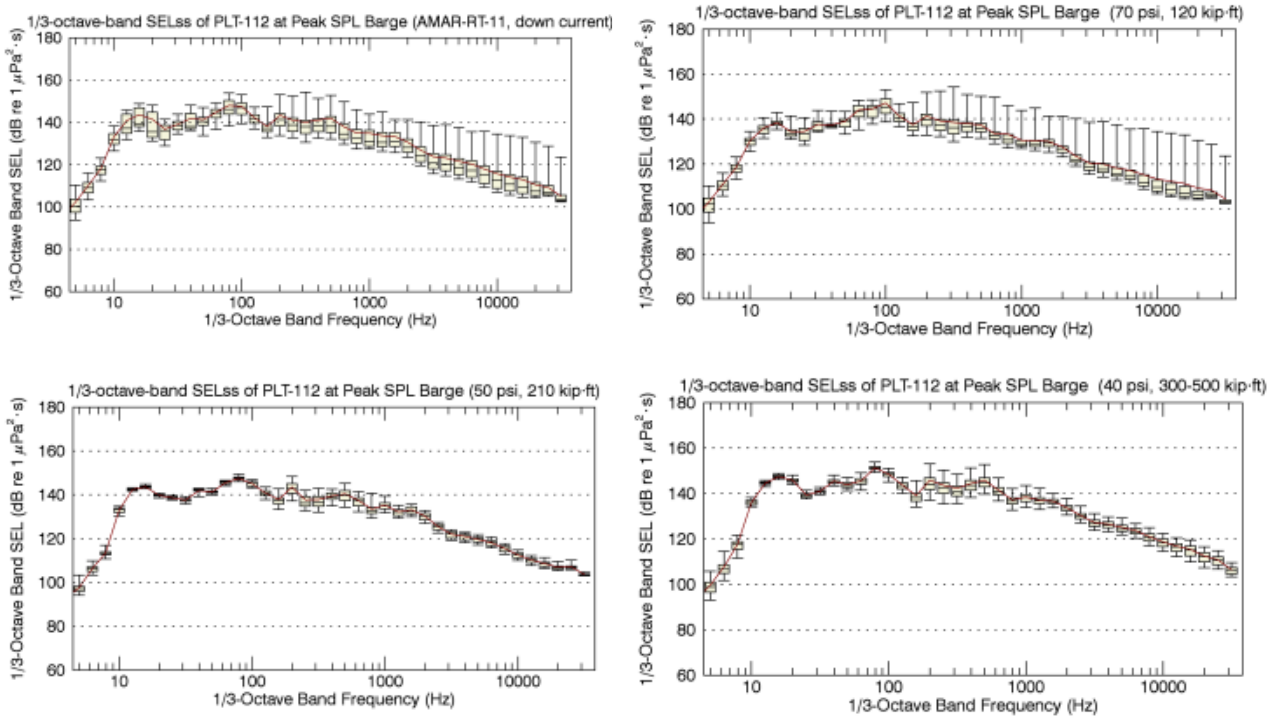

Figure 8. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112 measured 100 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 70 psi, 120 kip-ft. Bottom left: 50 psi, 210 kip-ft. Bottom right: 40 psi, 300–500 kip-ft.

Table 13. Sound levels for the pile driving of Test Pile PLT-112 measured 100 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	182.1	169.6	160.9
L_5	179.1	168.3	158.9
L_{25}	177.0	166.3	157.7
L_{50}	173.2	162.8	153.9
L_{75}	171.9	161.8	152.9
L_{95}	170.7	160.5	152.1
L_{mean}	172.4	161.9	153.2

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.2. Impact Pile-Driving Sound Levels from Peak SPL Vessel

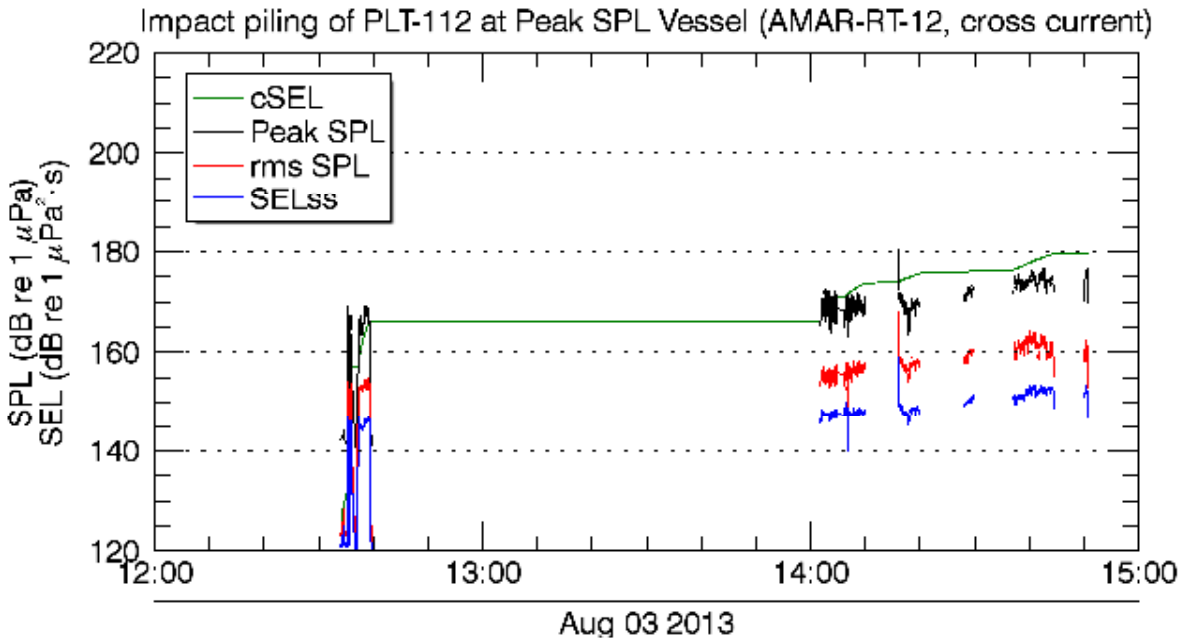

Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 170 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

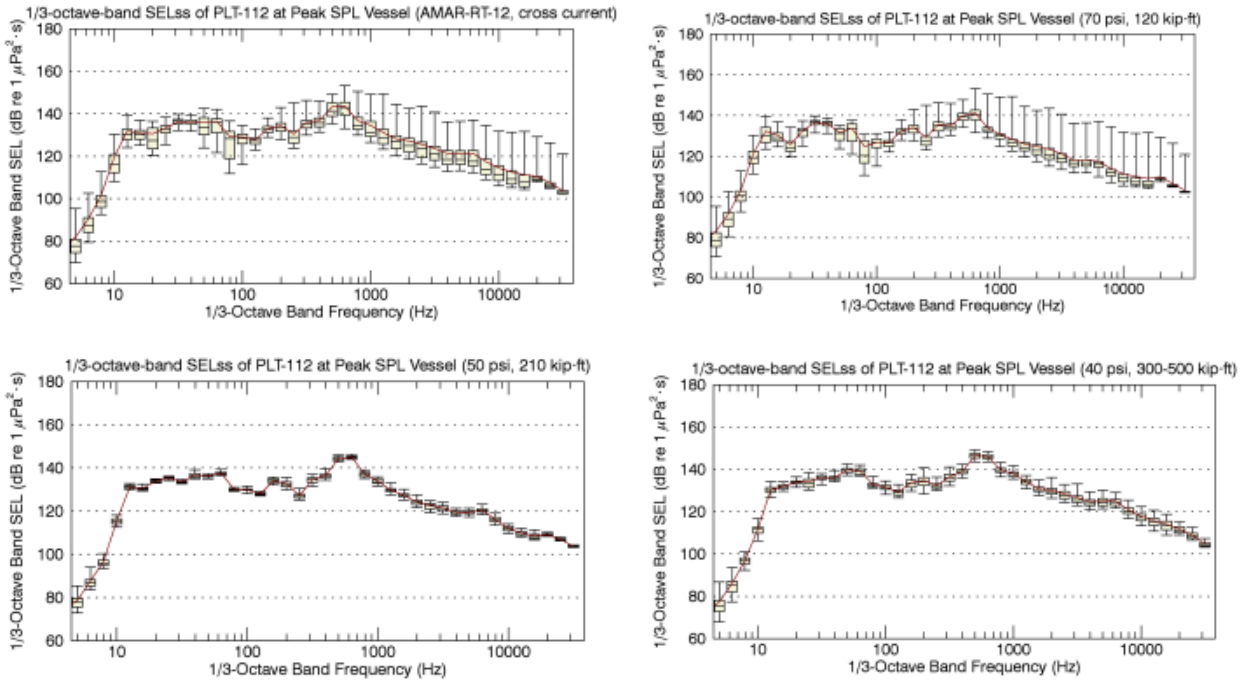

Figure 10. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112 measured 170 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 70 psi, 120 kip-ft. Bottom left: 50 psi, 210 kip-ft. Bottom right: 40 psi, 300–500 kip-ft.

Table 14. Sound levels for the pile driving of Test Pile PLT-112 measured 170 ft from the pile at location Peak SPL Vessel using AMAR-RT-12.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	180.3	167.9	159.0
L_5	175.4	163.0	153.0
L_{25}	173.6	160.5	151.5
L_{50}	170.4	157.9	148.7
L_{75}	168.5	156.2	147.7
L_{95}	166.4	154.4	146.7
L_{mean}	169.1	156.7	148.0

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.3. Impact Pile-Driving Sound Levels from cSEL East

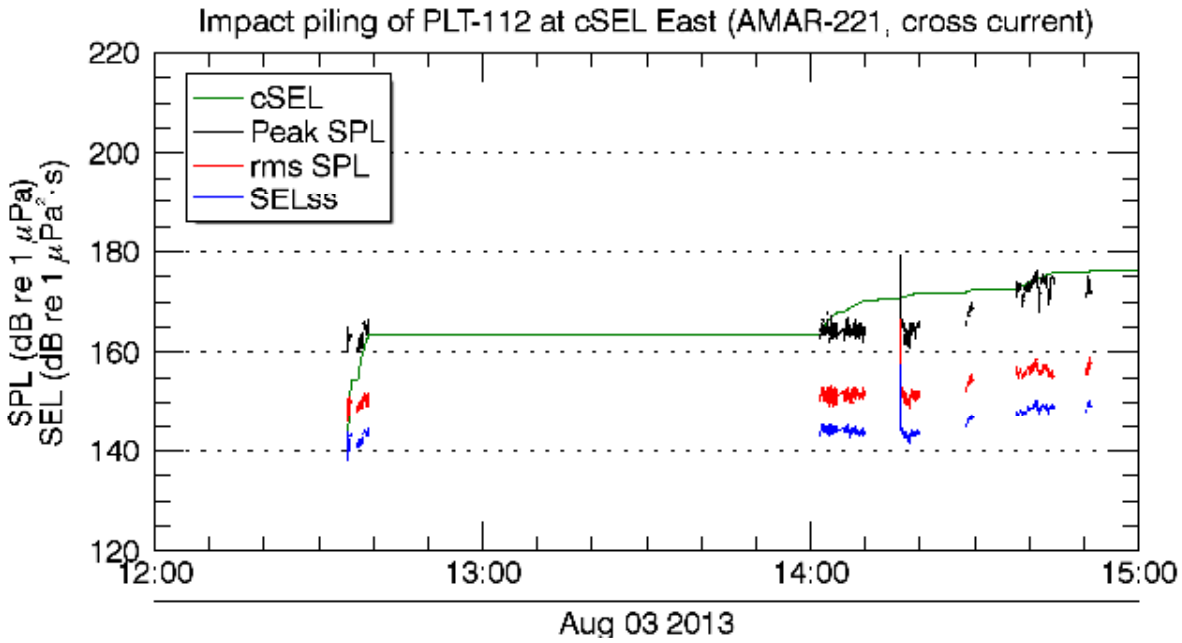

Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 282 ft from the pile at location cSEL East using AMAR-221. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

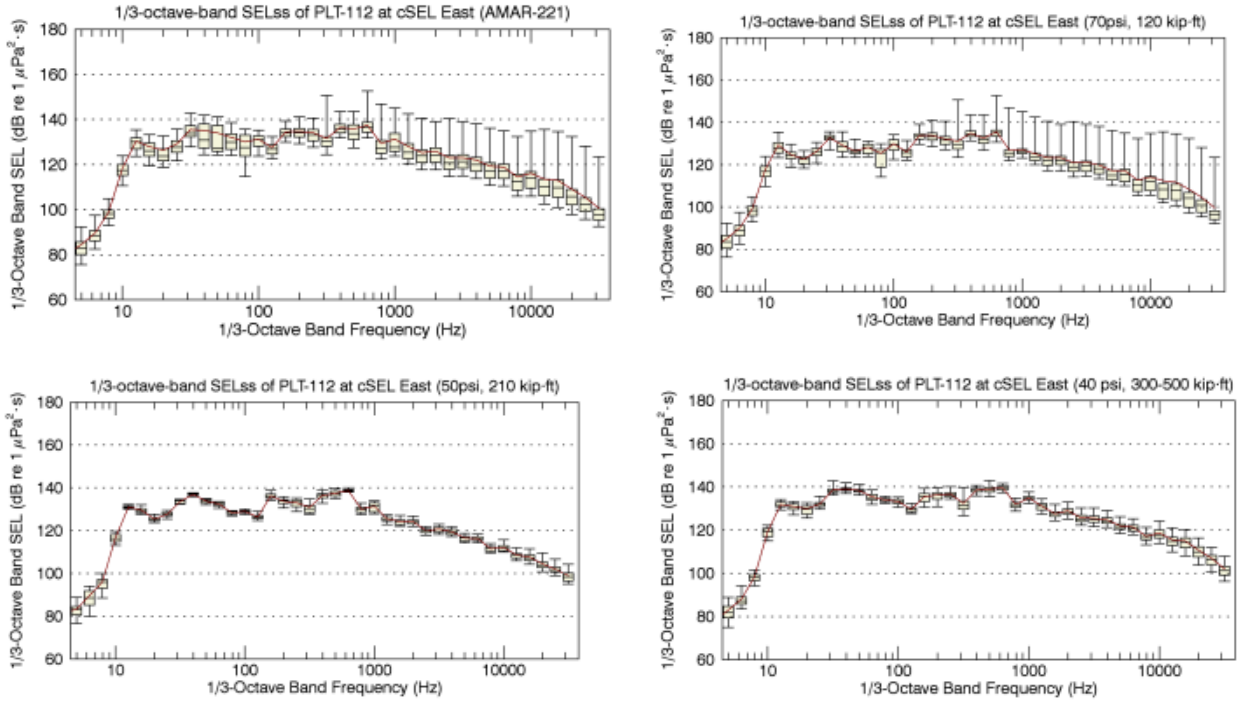

Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112 measured 282 ft from the pile at location cSEL East using AMAR-221. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 70 psi, 120 kip-ft. Bottom left: 50 psi, 210 kip-ft. Bottom right: 40 psi, 300-500 kip-ft.

Table 15. Sound levels for the pile driving of Test Pile PLT-112 measured 282 ft from the pile at location cSEL East using AMAR-221.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	179.3	166.3	157.4
L_5	174.7	157.4	149.5
L_{25}	172.4	155.7	148.3
L_{50}	165.6	152.4	144.5
L_{75}	164.1	151.4	143.7
L_{95}	162.9	150.2	142.9
L_{mean}	164.7	151.6	143.9

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.4. Impact Pile-Driving Sound Levels from cSEL North

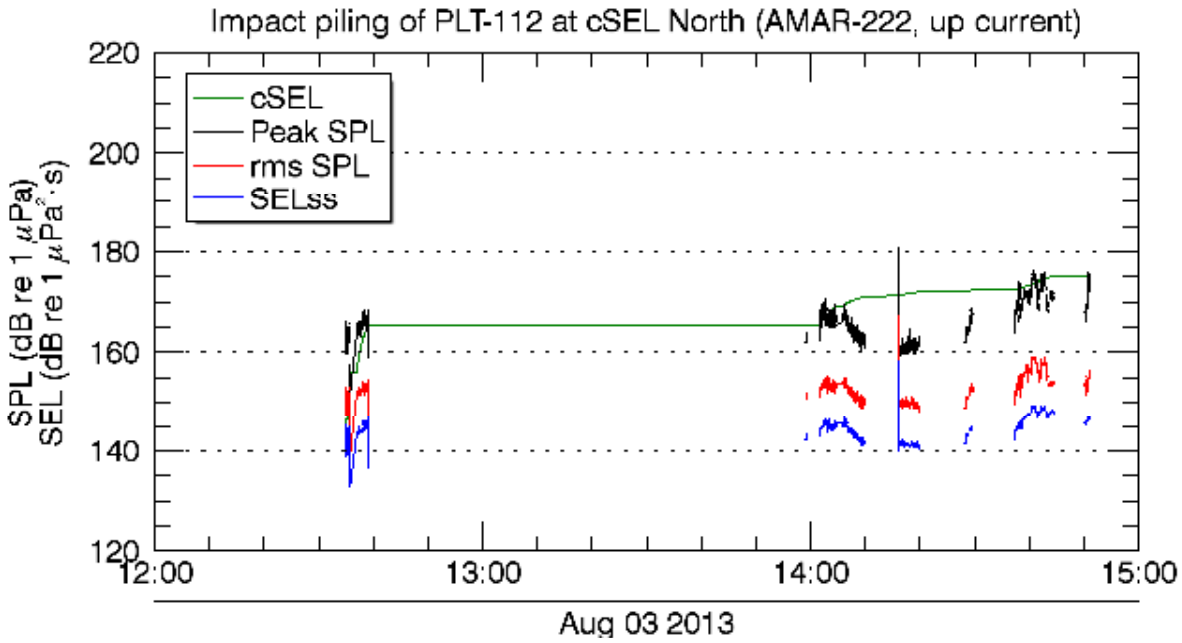

Figure 13. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 365 ft from the pile at location cSEL North using AMAR-222.Peak and rms sound pressure level (SPL) and cumulative sound exposure level (cSEL) versus time (EDT) measured at location cSEL North during pile driving at PLT-112 (365 ft from pile PLT-112, AMAR-222). For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

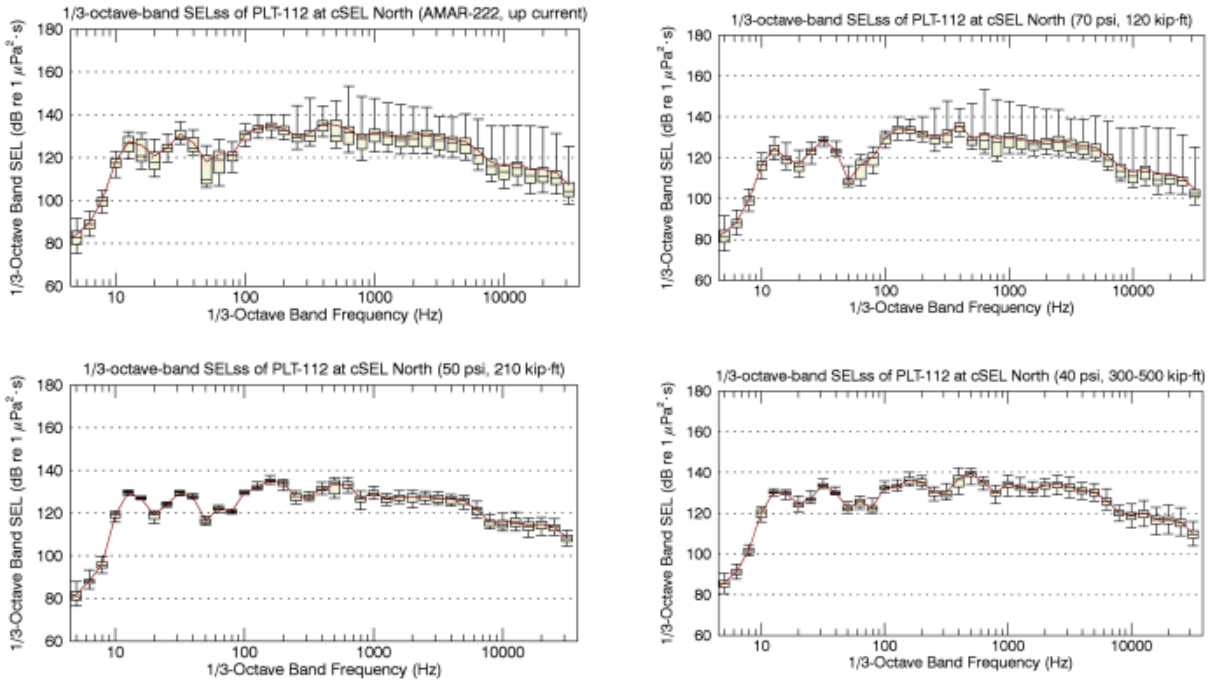

Figure 14. Distribution of /3-octave-band SELss for the pile driving of Test Pile PLT-112 measured 365 ft from the pile at location cSEL North using AMAR-222. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 70 psi, 120 kip-ft. Bottom left: 50 psi, 210 kip-ft. Bottom right: 40 psi, 300-500 kip-ft

Table 16. Sound levels for the pile driving of Test Pile PLT-112 measured 365 ft from the pile at location cSEL North using AMAR-222.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	180.8	167.4	158.3
L_5	174.5	157.9	148.7
L_{25}	169.8	154.3	146.4
L_{50}	166.4	152.8	144.6
L_{75}	162.5	150.5	142.0
L_{95}	160.3	149.2	140.9
L_{mean}	165.2	152.2	143.9

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.5. Impact Pile-Driving Sound Levels from cSEL South

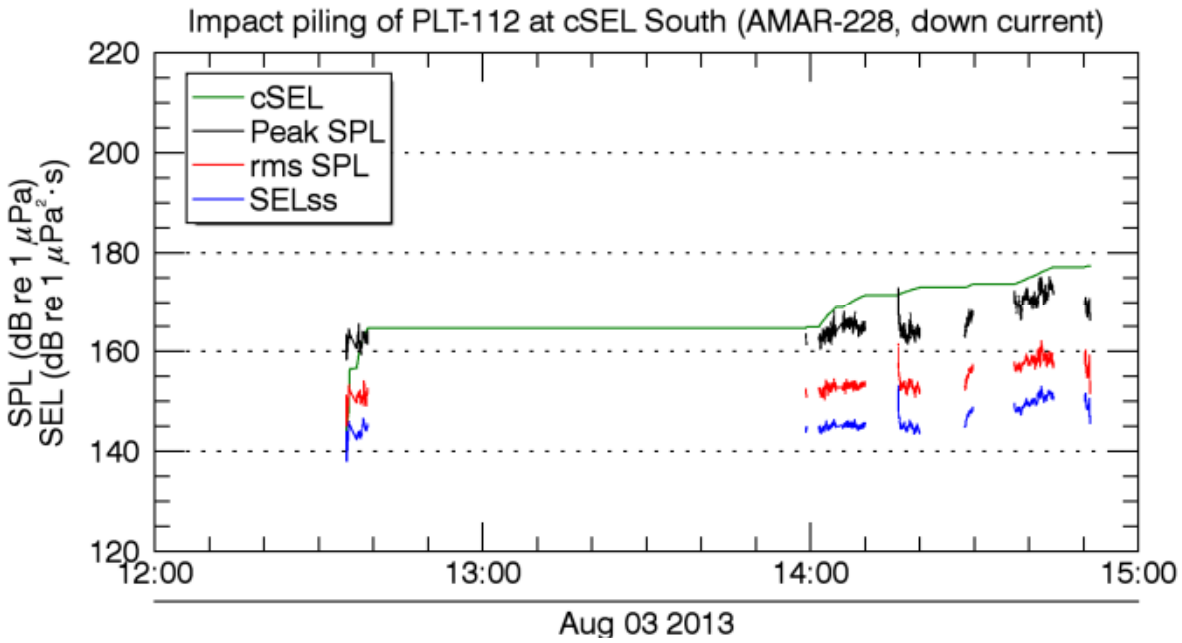

Figure 15. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 238 ft from the pile at location cSEL South using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

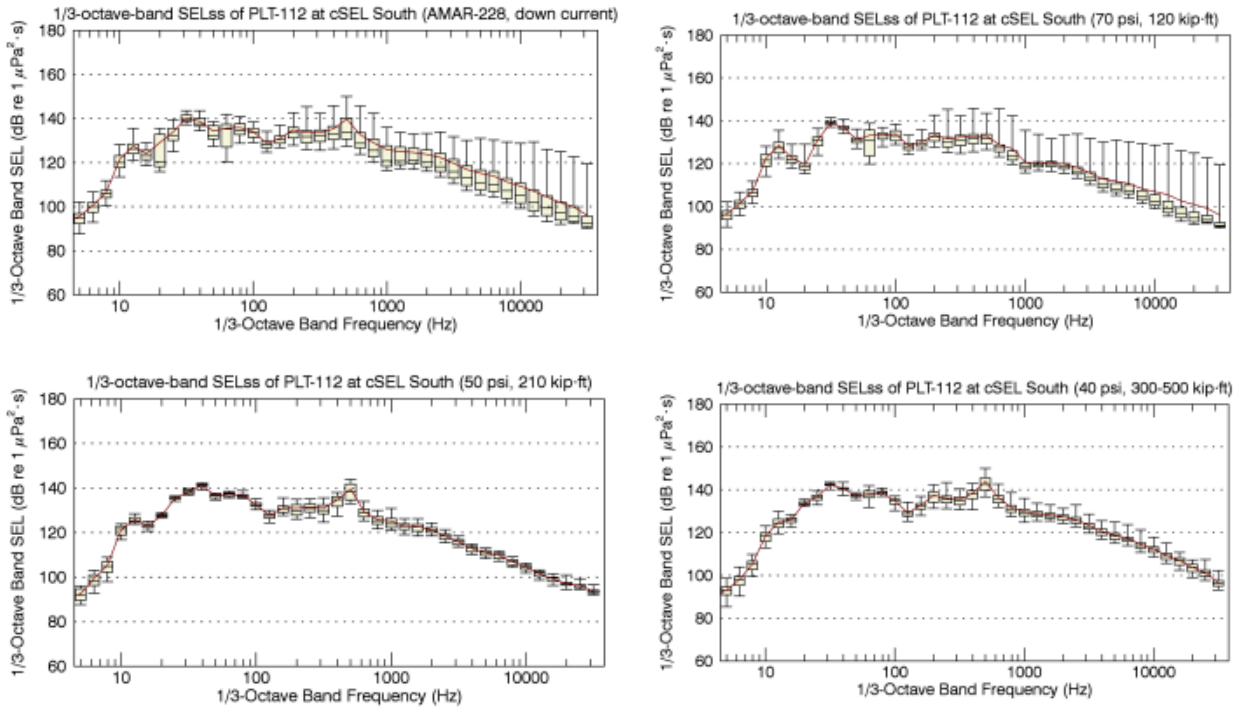

Figure 16. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112 measured 238 ft from the pile at location cSEL South using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 70 psi, 120 kip-ft. Bottom left: 50 psi, 210 kip-ft. Bottom right: 40 psi, 300-500 kip-ft

Table 17. Sound levels for the pile driving of Test Pile PLT-112 measured 238 ft from the pile at location cSEL South using AMAR-228.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa²·s)
L_{max}	175.2	162.1	153.2
L_5	172.9	159.3	151.5
L_{25}	169.9	157.2	149.0
L_{50}	165.4	153.6	145.5
L_{75}	163.9	152.7	144.9
L_{95}	162.3	151.8	144.1
L_{mean}	164.1	152.8	145.0

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 111 Installation

Daily Memorandum for 19 August 2013

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25 February 2014

P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-111 is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 19 August 2013 (Table 1). Two real-time acoustic monitoring systems and three autonomous acoustic monitoring systems deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors, LLC (TZC) (Table 2 and Figure 1). Pile driving occurred between 09:24–11:46 EDT. Full flood current occurred at 08:32 EDT, slowing to slack current at 11:45 EDT.

Table 2 provides the sound levels measured at each recorder. Plots of the measured values, frequency distributions of 1/3-octave-band single-strike sound exposure levels (SELss), and sound level statistics for the distribution of the measured data are presented in Appendix A.

Table 1. Summary of Test Pile PLT-111 activities, 19 August 2013.

Date:	19 August 2013
Pile-driving activity	
Test pile identifier:	PLT-111
Pile diameter:	[redacted]
Water depth:	42 ft
Hammer type:	Impact (IHC S-800)
Total hammer strikes:	[redacted]
Total penetration:	[redacted]
Net duration of pile driving (hh:mm:ss):	00:20:28
Maximum single strike energy:	339 thousand foot-pounds (kip-ft), (460 kJ)
Total energy transferred:	127,018 kip-ft (172 MJ)
Noise Attenuation System (NAS)	
Five-tier unconfined bubble curtain airflow rate:	800–2100 cubic feet per meter (cfm), 40–100 pounds per square inch (psi)
River conditions during pile driving:	Flood to slack current, 1.6–0.0 knots (0.8-0 meters per second [m/s] depth dependent; Table 9 and Figure 7)

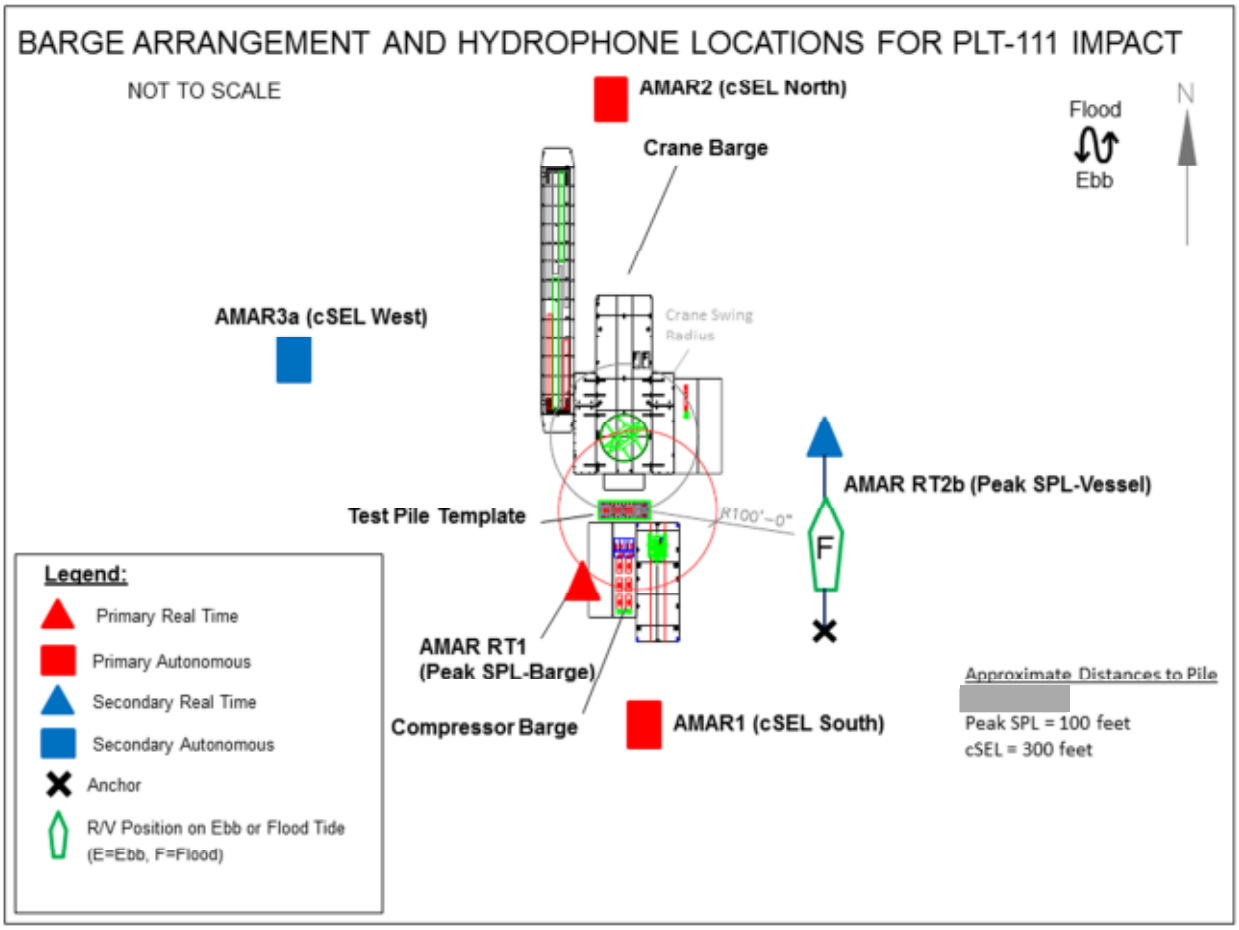

Figure 1. Plan view of pile and barge layout, 19 August 2013, PLT-111.

Table 2. Summary of Autonomous Multichannel Acoustic Recorder (AMAR) locations and measured sound levels. Detailed sound level plots are contained in Appendix A.

Location	Recorder ID	Distance to pile (ft)	Water depth (ft)	Max peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^{2}s)*
Peak SPL Barge (up current)	AMAR-RT-11	125	34	192	188
Peak SPL Vessel (cross current)	AMAR-RT-12	141	40	191	192
cSEL South (up current)	AMAR-221	396	45	184	184
cSEL West (cross current)	AMAR-222	268	39	186	183
cSEL North (down current)	AMAR-228	502	40	181	181

* Estimated at each recorder by multiplying the mean of the per-strike SEL by the number of strikes reported by the pile driving contractor, for the final value at the recorder, representing the total energy at the end of pile driving.

1.2. NMFS Physiological and Behavioral Thresholds

The distances from pile driving to the noise levels that serve as the National Marine Fisheries Service (NMFS) physiological and behavioral thresholds were extrapolated using a logarithmic regression based on mean values of the peak sound pressure levels (SPL), root mean square (rms) SPL, and SELss from each recorder (Table 3 and Figure 2).

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was approximately 6 ft and did not exceed NMFS criteria of a diameter of 100 ft for [redacted] piles. The diameter of the 187 dB re 1 µPa^2·s) cumulative sound exposure level (cSEL) isopleth was estimated to be approximately 400 ft at the end of pile driving. No other pile driving occurred during this pile load test. The river width is approximately 15,000 ft; therefore a fish movement corridor more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

Table 3. Estimated isopleth diameters for the NMFS physiological and behavioral thresholds.

Criteria	Estimated diameter ft
206 dB re 1 µPa peak SPL	6
187 dB re 1 µPa^2·s cSEL*	396
150 dB re 1 µPa rms SPL (1 s integration time)	6996

* At the end of pile driving

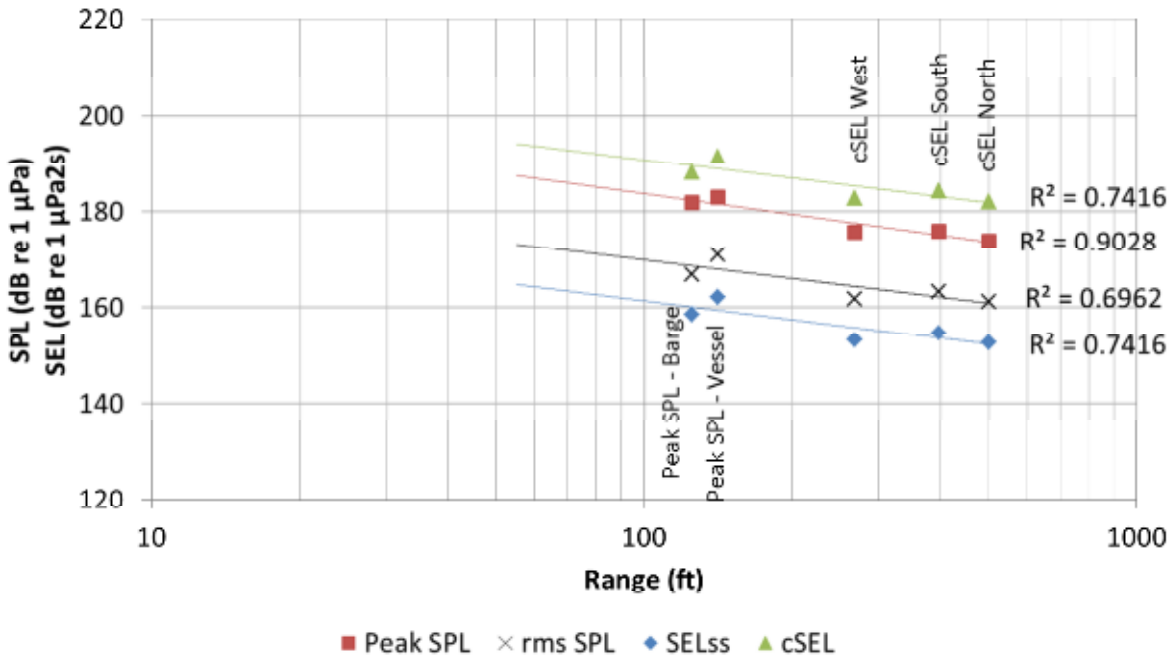

Figure 2. Regression based on mean values of the Peak SPL, rms SPLS, SELss and cSEL from each recorder from pile driving of Test Pile PLT-111, 19 August 2013. SELss, Peak SPL, and rms SPL are instantaneous values. The cSEL represents the cumulative Sound Exposure Level at the end of pile driving.

1.3. Observations

1.3.1. NAS Airflow Settings, River Currents, and Hammer Energy Effects

The impact hammer was operated at hammer energies of 123–138 kip-ft for most of the pile driving at PLT-111, rising to a maximum of 340 kip-ft (460 kJ) at refusal (Figure 3, Figure 5). The NAS air flow rate was increased from 40-60 psi (~1000 cfm) to 80-100 psi (~2000 cfm) when the hammer energy was increased (Figure 3, Table 8). PLT-111 was driven just after full flood current, and pile driving continued during slack current (Figure 3, Figure 7).

There was a significant decrease in the measured sound levels during the pile driving. Peak SPL, rms SPL, and SELss all appear to have dropped by 10–15 dB (Figure 3 shows SELss for all Locations).

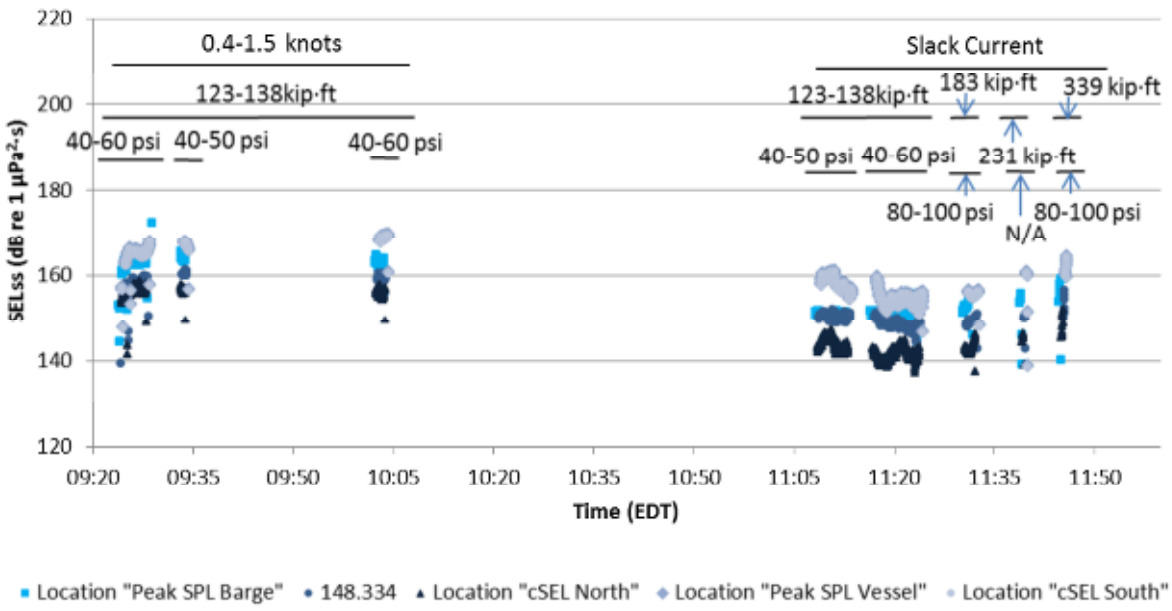

Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

The effects of river current conditions on the measured sound levels can be examined by comparing the measurements at 1.4 knots to slack current while the hammer energy and NAS settings were unchanged (Figure 3 and Table 4). Sound levels were 15 dB lower on average at locations cSEL West (cross-current) and cSEL North (down-current), but 10–12 dB lower for the other locations. This suggests that the NAS system was more effective at slack current than while the current was running. It is unclear why the levels at locations cSEL West and cSEL North were more affected than the others. In both current conditions the distances to sound levels were well below the required NMFS and NYSDEC thresholds (Table 5).

Table 4. Mean sound levels measured at 1.4 knots current and at slack tide during pile driving of PLT-111, 19 August 2013.

Location	Distance to pile (ft)	1.4 knots current			Slack current		
		Peak SPL[1]	rms SPL[1]	SELss[2]	Peak SPL[1]	rms SPL[1]	SELss[2]
Peak SPL Barge (up current)	125	186.6	171.7	163.3	173.2	157.2	151.3
Peak SPL Vessel (cross current)	141	187.6	175.3	166.4	175.7	165.3	156.4
cSEL South (up current)	396	180.3	167.5	158.9	169.2	157.6	149.3
cSEL West (cross current)	268	180.5	166.4	157.7	164.7	151.3	144
cSEL North (down current)	502	177.9	165.1	156.5	161.7	150.8	142.8

[1] dB re 1 µPa.

[2] dB re 1 µPa2·s.

Effects of current are found by subtracting the sound level at slack current from the level on the same recorder at 1.4 knots current. For example, peak SPL at location cSEL North was 177.9 dB at 1.4 knots and 161.7 dB at slack current, for a difference of 16.2 dB.

Table 5. Estimated isopleth diameters for the NMFS physiological and behavioral thresholds comparing estimates using the full data set, the results for 1.4 knots, and the results for slack current

Criteria	Estimated Diameter (ft) using full data set	Estimated Diameter (ft) 1.4 knots current	Estimated Diameter (ft) slack current
206 dB re 1 µPa peak SPL	6	15	5
187 dB re 1 µPa^2·s cSEL	396	836	140
150 dB re 1 µPa rms SPL (1 s integration time)	6996	12196	1402

It is also possible to compare the median sound levels at each recorder as a function of NAS setting and hammer energy at slack current (Table 6). Since all of these measurements were made at slack current, and all recorders were at very similar depths, we expect that differences in measured sound levels are due to either the increase in hammer energy or changed operation of the NAS system at the higher flow rates. There are no consistent patterns in the variations of the measured levels, which indicates that neither the increase in hammer energy nor the increase in air flow are having a predictable effect on the measured sound levels (Table 6). The inconsistency of the air flow, the rapidly changing hammer energies, and the low number of strikes mean the effect of changes in air flow at PLT-111 cannot be conclusively determined.

Table 6. Median sound levels measured during slack current to compare the effects NAS setting and hammer energy during pile driving of Test Pile PLT-111, 19 August 2013.

Location	Distance to pile (ft)	1650–2100 cfm (80–100 psi), slack current, 180–340 kip-ft (86 strikes)			800–1200 cfm (40–60 psi), slack current, 123–138 kip-ft (540 strikes)		
		Peak SPL[1]	rms SPL[1]	SELss[2]	Peak SPL[1]	rms SPL[1]	SELss[2]
Peak SPL Barge (up current)	125	174.6	158.4	153.8	173.2	157.2	151.3
Peak SPL Vessel (cross current)	141	177.6	162.1	155.6	175.7	165.3	156.4
cSEL South (up current)	396	170.5	155.1	149.2	169.2	157.6	149.3
cSEL West (cross current)	268	170.8	159.3	152.6	164.7	151.3	144
cSEL North (down current)	502	163.6	148.8	142.7	161.7	150.8	142.8

[1] Peak SPL and rms SPL units are dB re 1 µPa.

[2] SELss units are dB re 1 µPa^2·s.

Effects of changing settings are found by subtracting the sound levels from the 1650–2100 cfm measurements from the levels on the same recorder at 800–1200 cfm. For example, peak SPL at location cSEL North was 163.6 dB at 1650–2100 cf, and 161.7 dB at 800–1200 cfm, for a difference of 1.9 dB.

1.3.2. Growth of the cSEL Isopleth

The cSEL presented in the figures and tables of this section represent the total energy at the end of pile driving measured at each recorder and the estimated diameter of the area which received 187 dB re 1 µPa^2·s cSEL. Figure 4 depicts how the diameter of the 187 dB re 1 µPa^2·s cSEL area increases over the pile driving period of PLT-111.

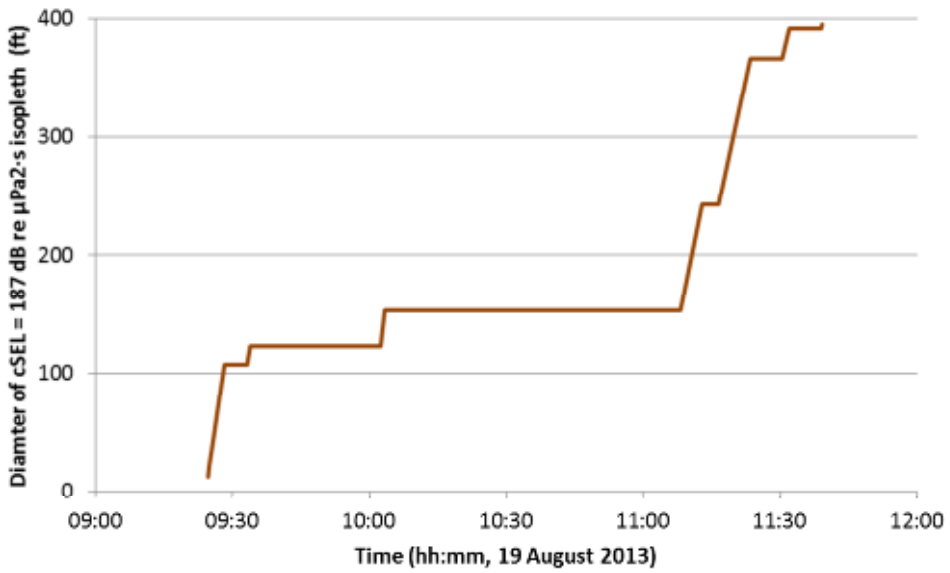

Figure 4. Estimated diameter of the area around Test Pile PLT-111 where cSEL exceeded 187 dB re 1 µPa^2·s as a function of time. Flat sections are time periods without pile driving.

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 7 provides activities for 19 September 2013.

Table 7. JASCO and construction activities for Test Pile PLT-111, 19 September 2013.

Time (EDT)	Activity
06:30	Safety meeting on shore
07:30	Embark from Cornetta's
08:15	Deploy AMAR-221, AMAR-222, and AMAR-228
08:20	Deploy AMAR-RT-11 from barge
08:35	Start picking hammer
09:18	Deploy AMAR-RT-12 from Alpine Vessel
09:20	Position hammer on PLT-111
09:24	Start pile driving
10:45	CTD cast from barge
11:59	Stop pile driving
12:00	Retrieve AMAR-RT-12
12:10	Retrieve AMAR-RT-11
12:10	Begin retrieval of autonomous AMARs (shut down ADCP)
12:50	Complete retrieval of autonomous AMARs
14:15	All work complete

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: five-tier unconfined bubble curtain

NAS settings: 800–2100 cfm, 40–100 psi

Table 8. NAS setting recorded by during pile driving at Test Pile PLT-111, 19 August 2013.

Time (EDT)	Volume/min (cfm)	Pressure (psi)
09:25–09:29	800–1200	40–60
09:33–09:34	900–1100	40–50
10:03–10:04	1000–1100	40–60
11:09–11:13	1000–1100	40–50
11:17–11:24	1000–1200	40–60
11:31–11:32	1650–2100	80–100
11:39 (11 strikes)	No readings	No readings
11:45–11:46	1650–2100	80–100

2.2.2. Impact Hammering Log

Total energy: 127,018 kip-ft (172 MJ)

Total number of strikes: [redacted]

Maximum per-strike energy: 339 kip-ft (460 kJ)

Net pile driving duration (hh:mm:ss): 00:20:28

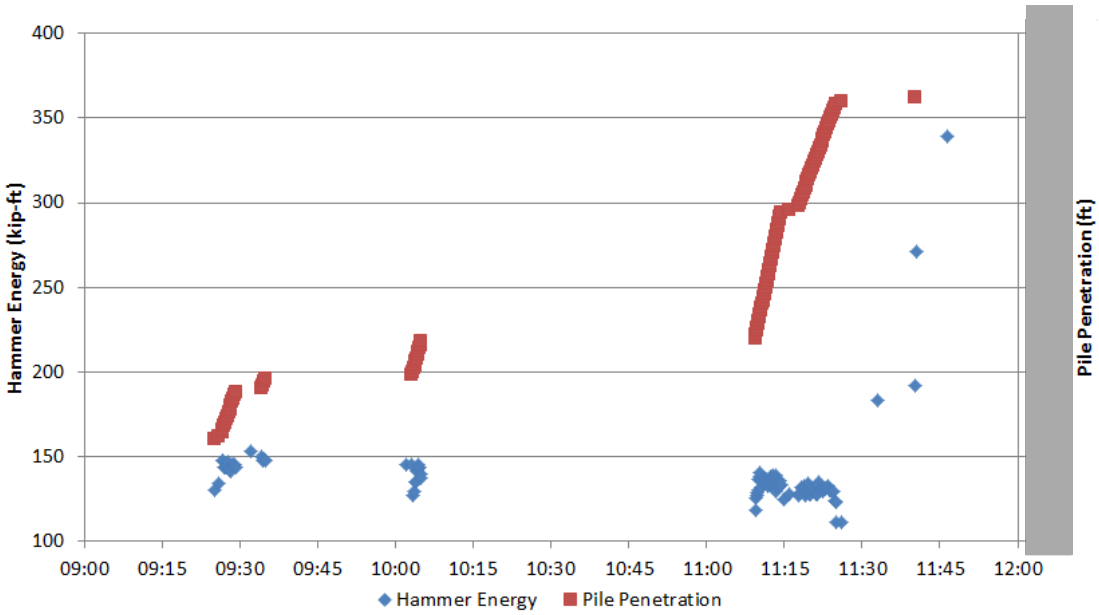

Figure 5. Hammer energy (kip-ft) and pile penetration (ft) for the impact pile driving of PLT-111, 19 August 2013.

3. Weather and River Conditions

Table 9 provides the predicted currents at the project site on 19 August 2013. Figure 6 provides measured currents at the project site on 19 August using an Acoustic Doppler Current Profiler (ADCP). Figure 7 provides the measured speed of sound in water, based on a conductivity, temperature, depth (CTD) cast.

Table 9. Weather conditions, current, and predicted local tide times (EDT).

Weather conditions:	Mainly sunny, Sea State 1-2, 3–5 knot southerly wind
Full flood current:	08:48 (1.0 knots)
Slack current:	11:45
Full ebb current:	15:11 (2.2 knots)

Reference: http://tidesandcurrents.noaa.gov/get_predc.shtml?year=2013&stn=0611+George Washington Bridge&secstn=Tappan+Zee+Bridge&sbfh=%2B1&sbfm=12&fldh=%2B0&fldm=55&sbeh=%2B0&sbem=52&ebbh=%2B1&ebbm=06&fldr=0.6&ebbr=0.8&fldavgd=356&ebbavgd=175&footnote=

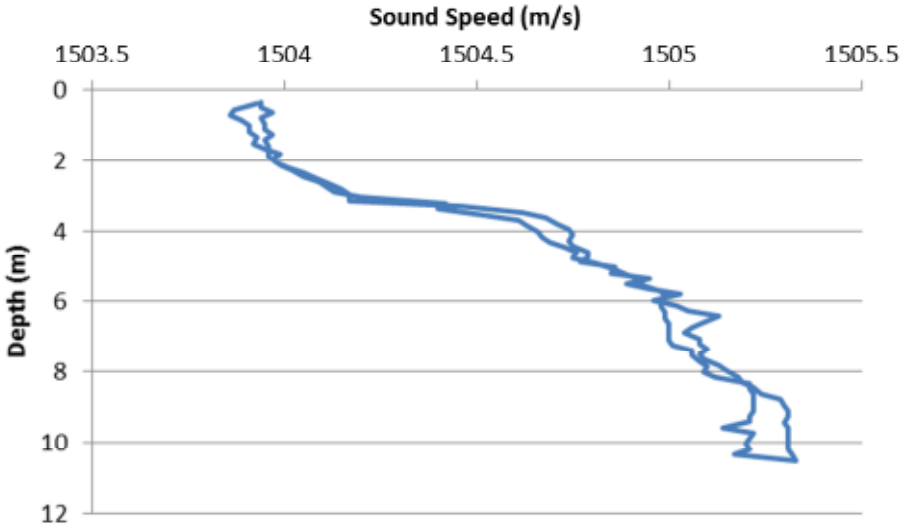

Figure 6. CTD cast performed at 10:45 EDT at location Peak SPL Barge located 125 ft south of Test Pile PLT-104 (41.07100N, 73.88355W)..

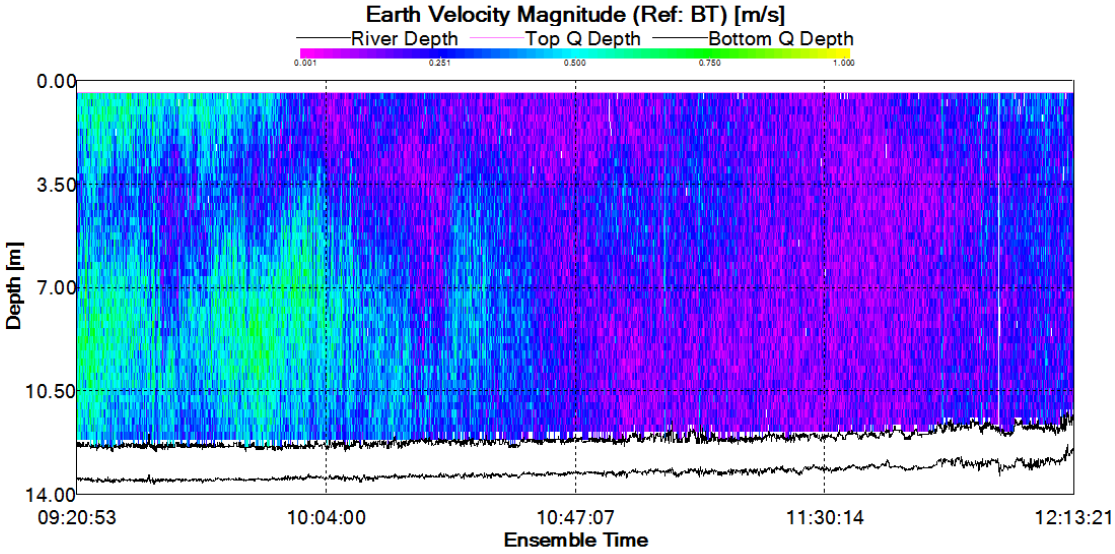

Figure 7. ADCP data from 19 August 2013 from location Peak SPL Vessel. Times are in EDT.

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 10 provides information on the real-time monitoring equipment used on 19 August 2013. Table 11 provides location information on the real-time recorders.

Table 10. Real-time monitoring equipment for Test Pile PLT-111,19 August 2013.

Equipment used		Units deployed
Acoustic data logger		
Model:	AMAR RT (JASCO Applied Sciences)	2
SpectroPlotter version:	6.0.1	2
Hydrophone		
Model:	M8KC (GTI)	2
AMAR-RT-11 sensitivity:	−210.9 dB re 1 V/µPa	1
AMAR-RT-12 sensitivity:	−210.8 dB re 1 V/µPa	1
Other		
Hydrophone calibrator:	Pistonphone Type 42AC (G.R.A.S. Sound and Vibration)	1
CTD profiler:	Minos X (AML Oceanographic)	1
ADCP:	RDI Teledyne Workhorse Sentinel 1200 kHz	1

Table 11. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 19 August 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
Peak SPL Barge (up current)	AMAR-RT-11	41.07110	73.88346	08:20	35	125
Peak SPL Vessel (cross current)	AMAR-RT-12	41.07157	73.88295	09:18	40	141

4.2. Autonomous Monitoring Equipment

Table 12 provides information on the autonomous monitoring equipment used on 19 August 2013. Table 13 provides the locations of the autonomous recorders.

Table 12. Autonomous monitoring equipment for Test Pile PLT-111, 19 August 2013.

Equipment used		Units deployed
Acoustic data logger		
Model:	AMAR G3 (JASCO Applied Sciences)	3
SpectroPlotter version:	6.0.1	3
Hydrophone		
Model:	M8E-51-0dB (GTI)	3
AMAR-221 sensitivity:	–199.9 dB re 1 V/µPa	1
AMAR-228 sensitivity:	–199.7 dB re 1 V/µPa	1
AMAR 228 sensitivity:	–199.7 dB re 1 V/µPa	1

Table 13. Locations (WGS84) and deployment times (EDT) of the autonomous AMAR monitoring stations 19 August 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
cSEL South (up current)	AMAR-221	41.07044	73.88290	07:41	45	396
cSEL West (cross current)	AMAR-222	41.07159	73.88437	08:12	39	268
cSEL North (down current)	AMAR-228	41.07283	73.88339	08:02	40	502

Appendix A. Pile Driving Plots

A.1. Impact Pile-Driving Sound Levels from Peak SPL Barge

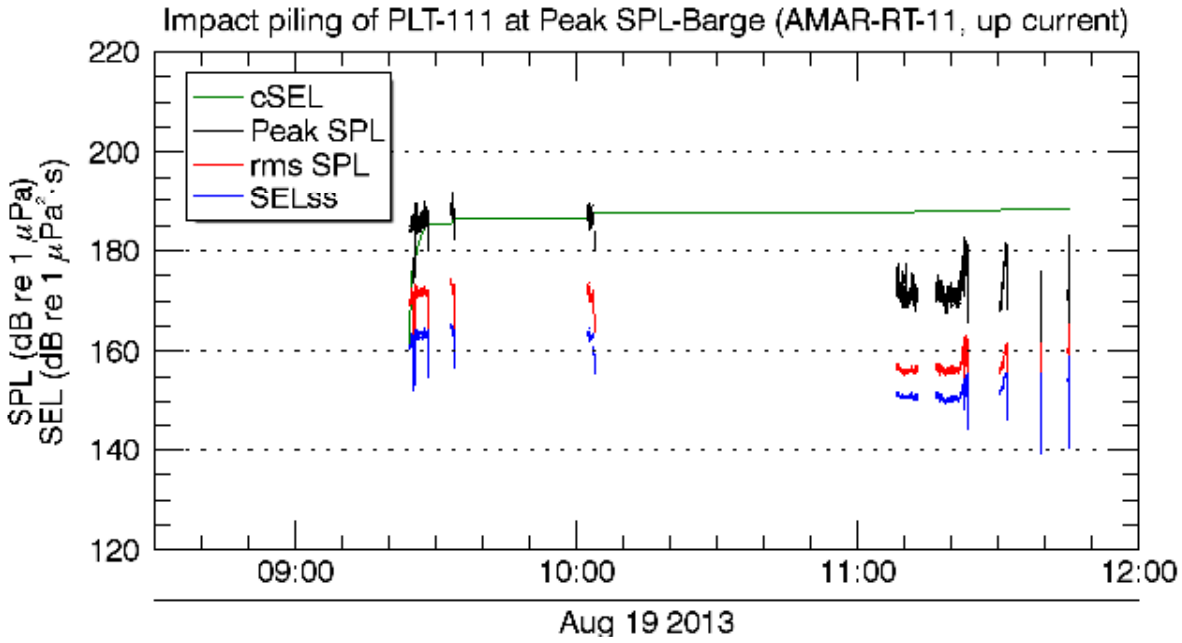

Figure 8. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL for the pile driving of Test Pile PLT-111 measured 125 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

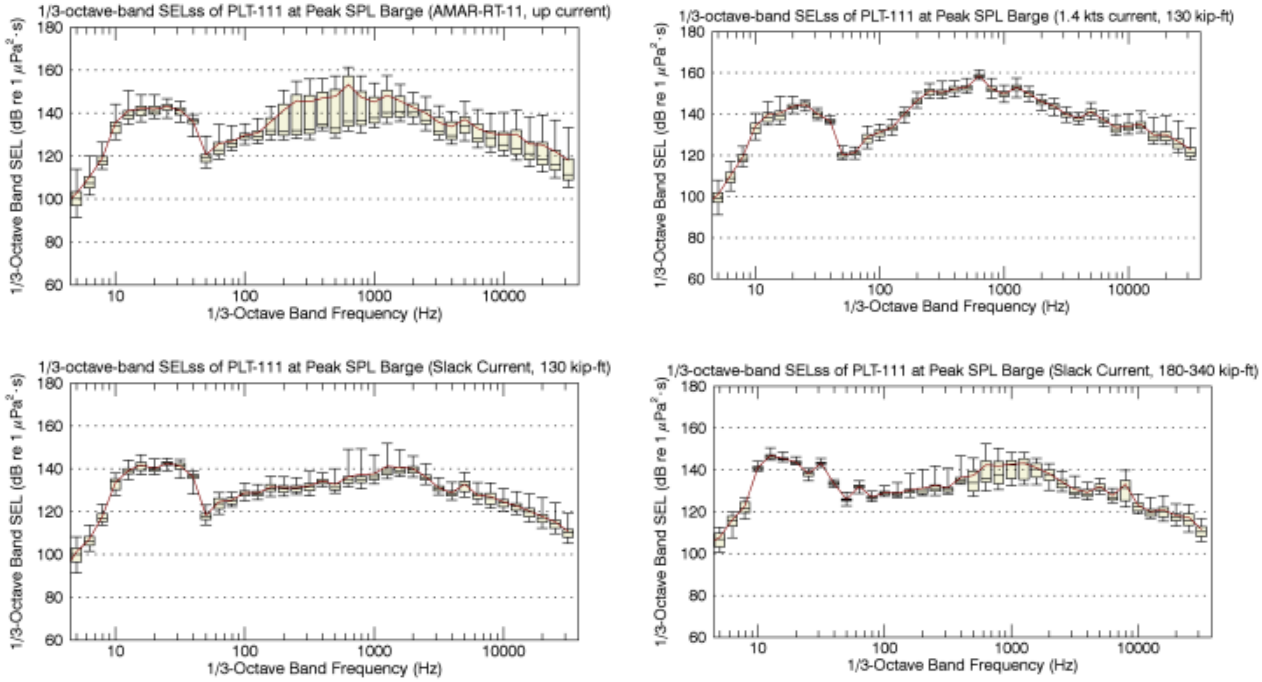

Figure 9. Distribution of one-second 1/3-octave-band SELss for the pile driving of Test Pile PLT-111 measured 125 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 1.4 knots current, 130 kip-ft (260 strikes). Bottom left: slack current, 130 kip-ft (540 strikes). Bottom right: slack current, 180-340 kip-ft (89 strikes).

Table 14. Sound levels for the pile driving of Test Pile PLT-111 measured 125 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	191.9	174.3	165.5
L_5	187.8	172.5	164.1
L_{25}	184.8	170.7	162.5
L_{50}	173.0	157.1	151.6
L_{75}	170.8	156.2	150.8
L_{95}	169.2	155.5	150.1
L_{mean}	181.8	166.7	158.6

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.2. Impact Pile-Driving Sound Levels from Peak SPL Vessel

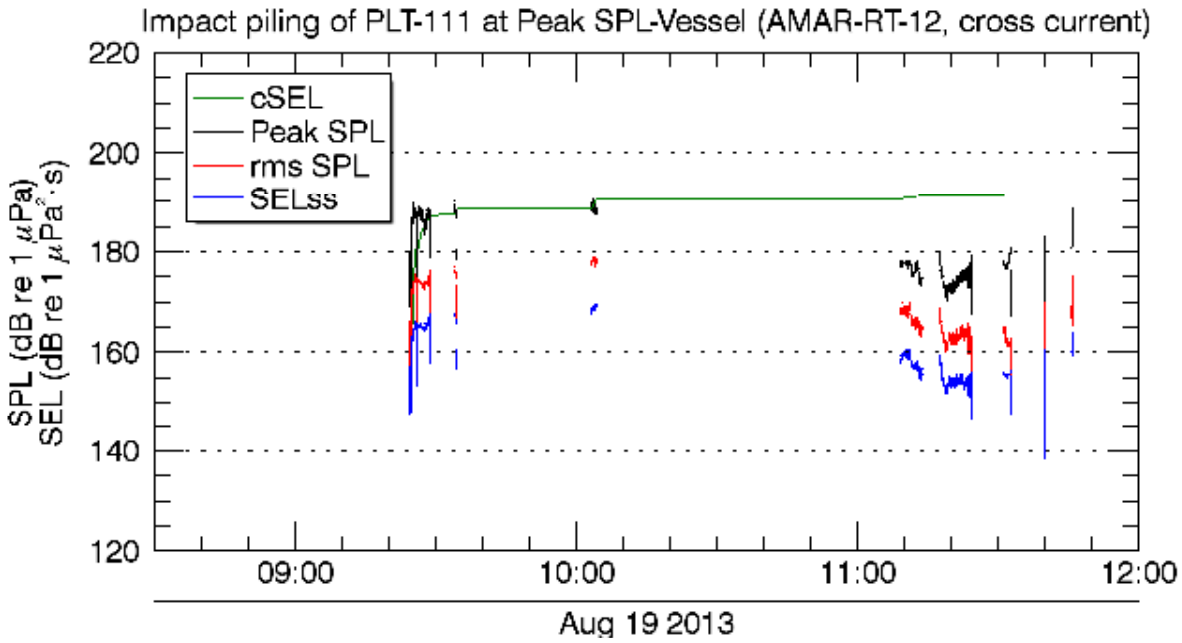

Figure 10. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL for the pile driving of Test Pile PLT-111 measured 141 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

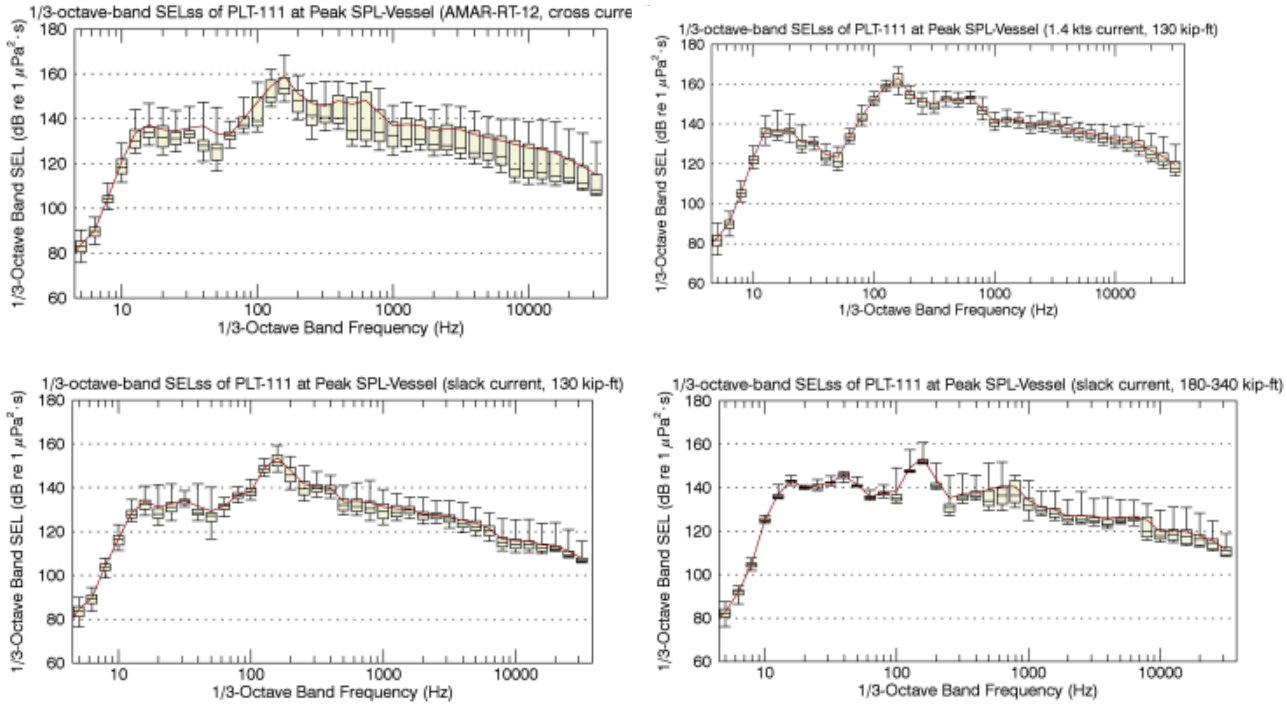

Figure 11. Distribution of one-second 1/3-octave-band SELss for the pile driving of Test Pile PLT-111 measured 141 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 1.4 knots current, 130 kip-ft (260 strikes). Bottom left: slack current, 130 kip-ft (540 strikes). Bottom right: slack current, 180–340 kip-ft (89 strikes).

Table 15. Sound levels for the pile driving of Test Pile PLT-111 measured 141 ft from the pile at location Peak SPL Vessel using AMAR-RT-12.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	190.6	178.9	169.6
L_5	188.6	177.7	168.3
L_{25}	186.0	173.1	164.4
L_{50}	177.2	165.5	156.9
L_{75}	174.8	163.1	154.4
L_{95}	166.4	154.4	146.7
L_{mean}	183.0	170.9	162.0

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.3. Impact Pile-Driving Sound Levels from cSEL South

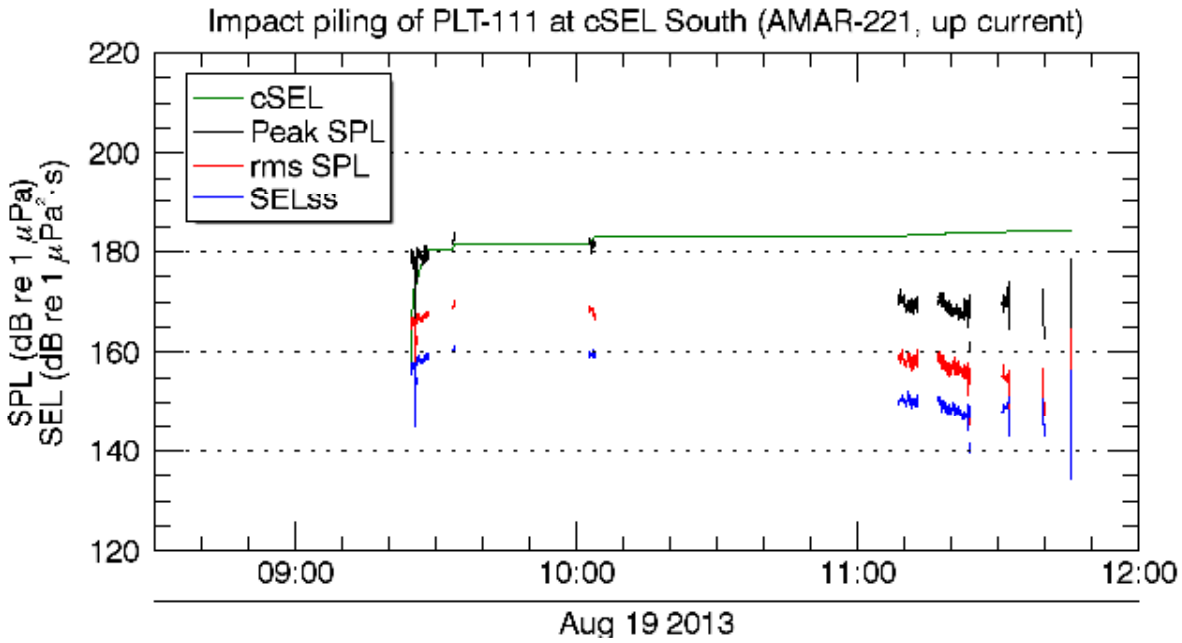

Figure 12. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL for the pile driving of Test Pile PLT-111 measured 396 ft from the pile at location cSEL South using AMAR-221. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

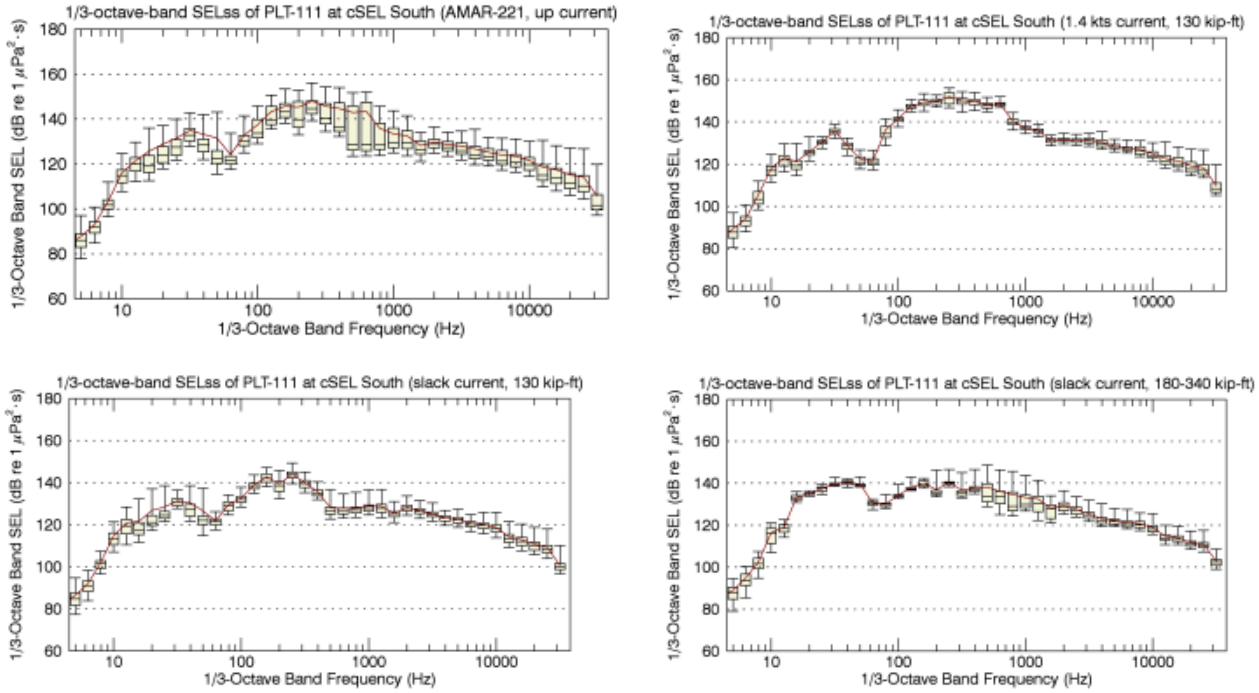

Figure 13. Distribution of one-second 1/3-octave-band SELss for the pile driving of Test Pile PLT-111 measured 396 ft from the pile at location cSEL South using AMAR-221. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 1.4 knots current, 130 kip-ft (260 strikes). Bottom left: slack current, 130 kip-ft (540 strikes). Bottom right: slack current, 180–340 kip-ft (89 strikes).

Table 16. Sound levels for the pile driving of Test Pile PLT-111 measured 396 ft from the pile at location cSEL South using AMAR-221.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	183.9	170.5	161.4
L_5	181.7	168.5	159.9
L_{25}	178.2	166.2	157.8
L_{50}	170.1	158.0	150.1
L_{75}	168.6	156.6	148.7
L_{95}	167.5	154.9	147.2
L_{mean}	175.8	163.1	154.6

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (Ln) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.4. Impact Pile-Driving Sound Levels from cSEL West

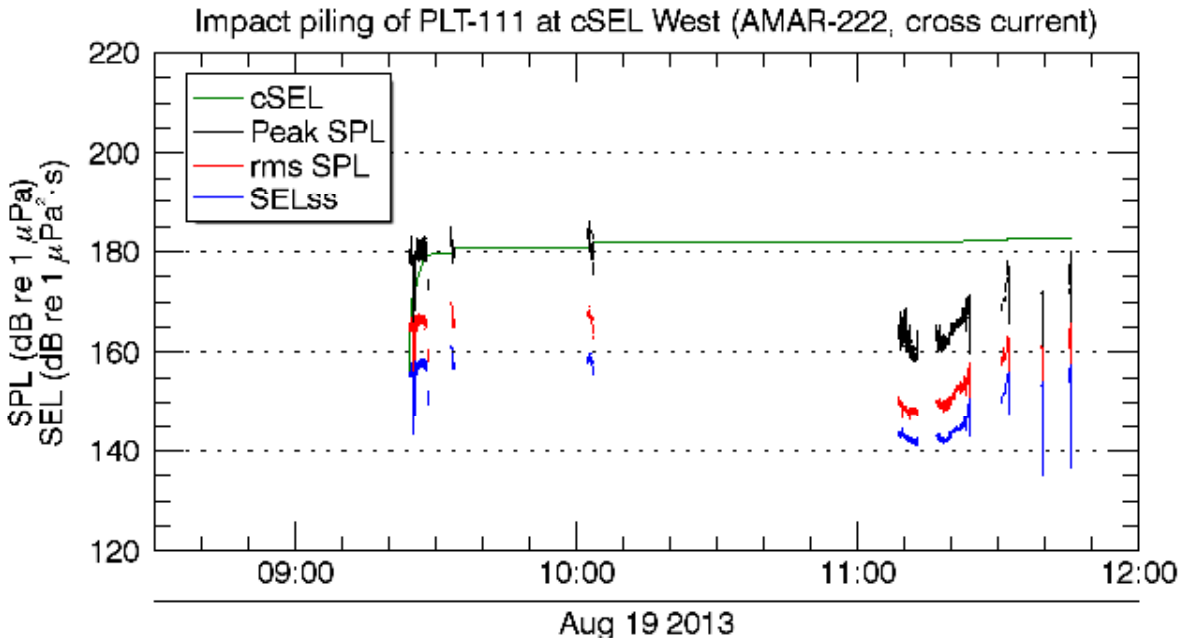

Figure 14. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL for the pile driving of Test Pile PLT-111 measured 268 ft from the pile at location cSEL West using AMAR-222. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

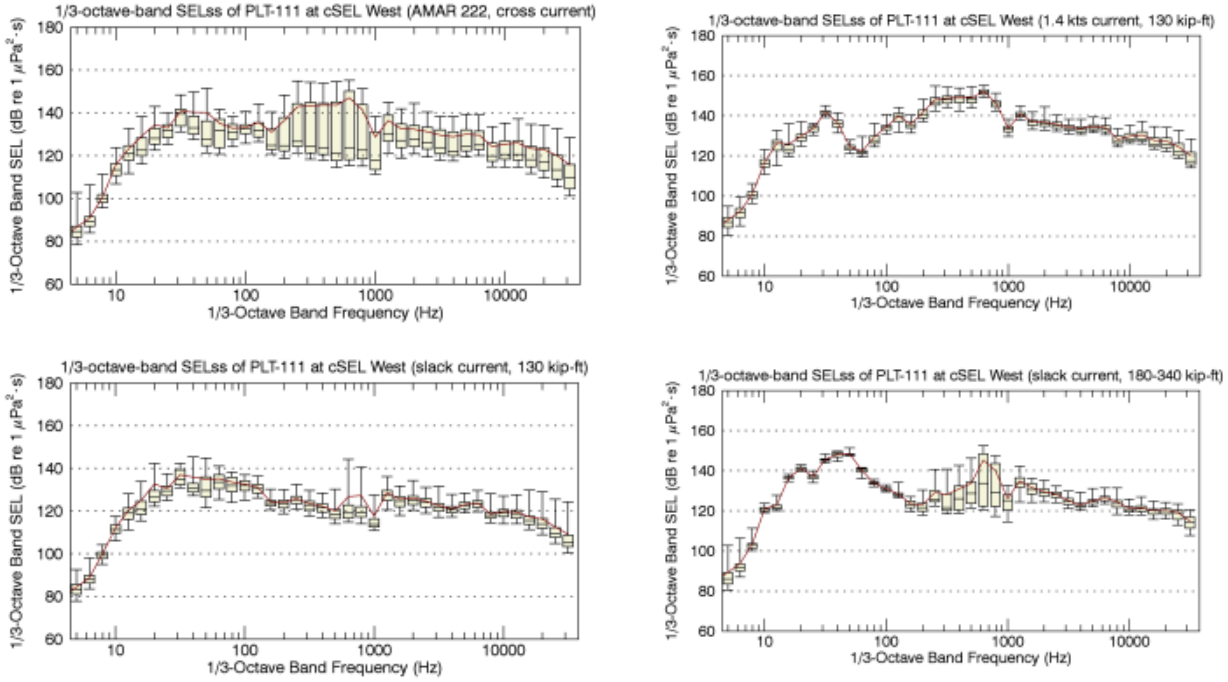

Figure 15. Distribution of one-second 1/3-octave-band SELss for the pile driving of Test Pile PLT-111 measured 268 ft from the pile at location cSEL West using AMAR-222. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 1.4 knots current, 130 kip-ft (260 strikes). Bottom left: slack current, 130 kip-ft (540 strikes). Bottom right: slack current, 180–340 kip-ft (89 strikes).

Table 17. Sound levels for the pile driving of Test Pile PLT-111 measured 268 ft from the pile at location cSEL West using AMAR-222.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	186.1	169.9	161.4
L_5	181.6	167.4	158.5
L_{25}	178.4	164.7	156.1
L_{50}	166.3	153.0	144.8
L_{75}	162.7	149.5	142.7
L_{95}	159.8	148.0	141.7
L_{mean}	175.6	161.7	153.2

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.5. Impact Pile-Driving Sound Levels from cSEL North

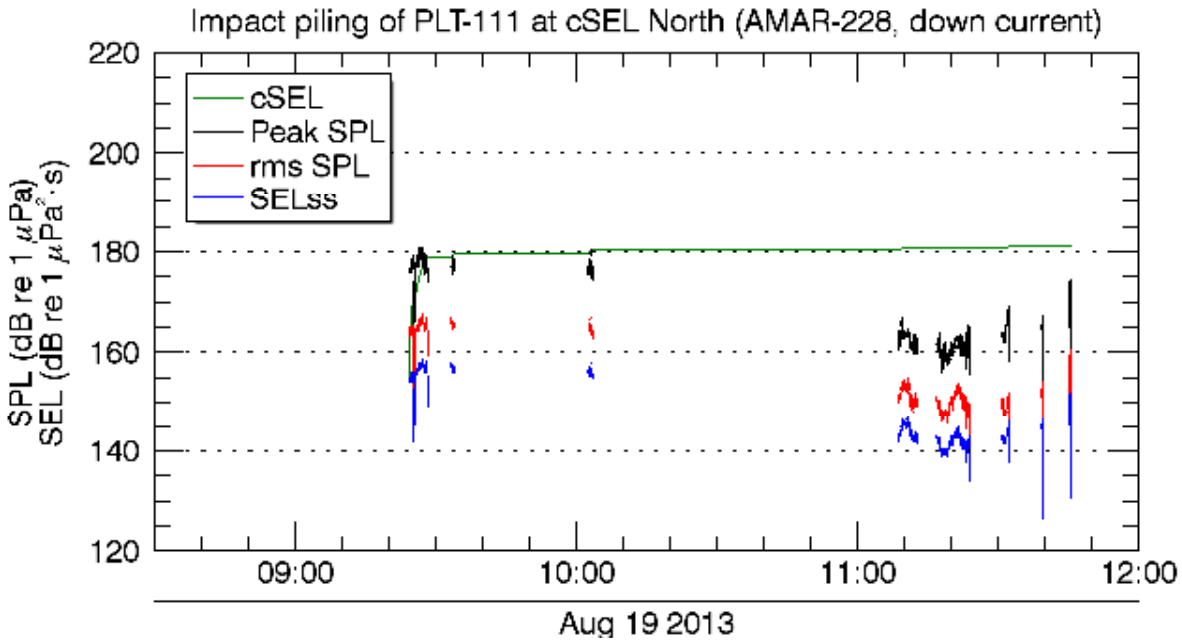

Figure 16. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL for the pile driving of Test Pile PLT-111 measured 502 ft from the pile at location cSEL North using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

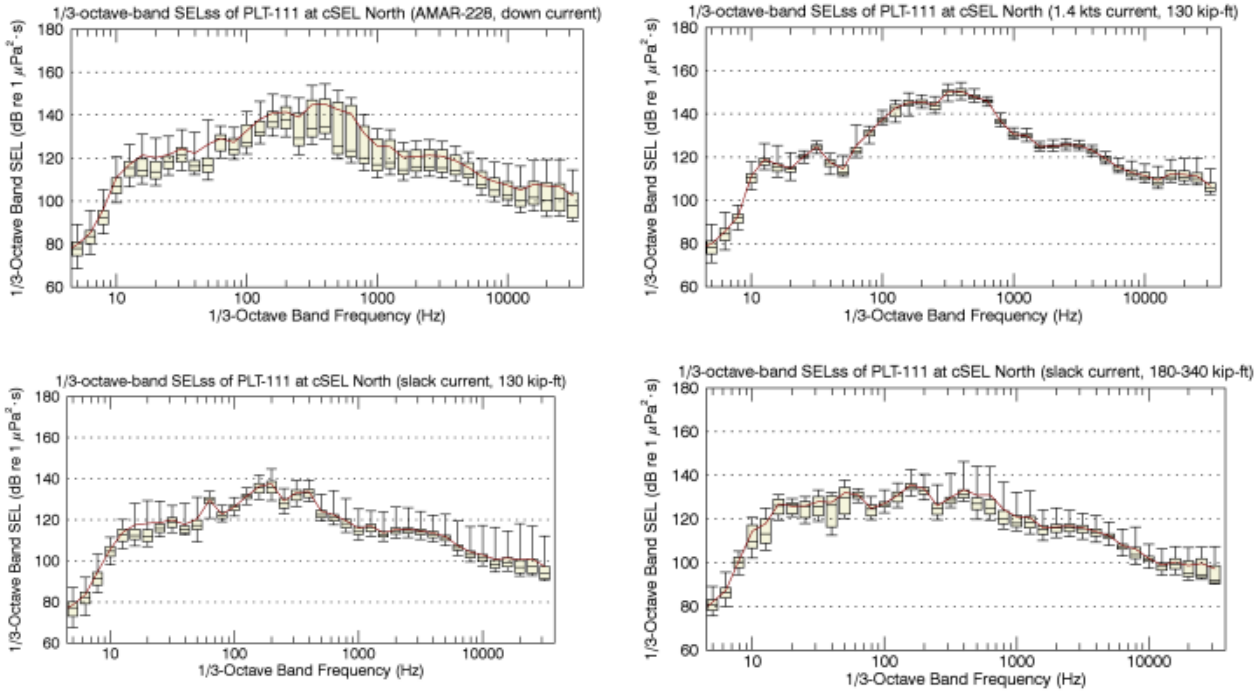

Figure 17. Distribution of one-second 1/3-octave-band SELss for the pile driving of Test Pile PLT-111 measured 502 ft from the pile at location cSEL North using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}). Top left: all NAS settings. Top right: 1.4 knots current, 130 kip-ft (260 strikes). Bottom left: slack current, 130 kip-ft (540 strikes). Bottom right: slack current, 180–340 kip-ft (89 strikes).

Table 18. Sound levels for the pile driving of Test Pile PLT-111 measured 502 ft from the pile at location cSEL North using AMAR-228.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	180.8	167.6	158.7
L_5	179.4	166.4	157.6
L_{25}	177.0	164.5	155.9
L_{50}	163.1	152.5	144.1
L_{75}	160.8	150.1	142.4
L_{95}	158.4	147.3	139.9
L_{mean}	172.8	160.1	151.5

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 110 Installation

Daily Memorandum for 06 September 2013

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17 March 2014

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1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-110 is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 06 September 2013 (Table 1). One real-time acoustic monitoring system and three autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors, LLC (TZC) (Figure 1 and Table 2). Pile driving occurred between 16:19–17:34 Eastern Daylight Time (EDT), and full ebb current occurred at 17:09 EDT.

Table 2 provides the sound levels measured at each recorder. Plots of the measured values, frequency distributions of 1/3-octave-band single-strike sound exposure levels (SELss), and sound level statistics for the distribution of the measured data are presented in Appendix A.

Table 1. Summary of Test Pile PLT-110 activities, 06 September 2013.

Date:	06 September 2013
Pile-Driving Activity	
Test pile identifier:	PLT-110
Pile diameter:	[redacted]
Water depth:	18 ft
Hammer type:	Impact (IHC S-800)
Total hammer strikes:	[redacted]
Total penetration:	[redacted]
Net duration of pile driving (hh:mm:ss):	00:25:11
Maximum single strike energy:	283.3 thousand foot-pounds (kip-ft), (384 kJ)
Total energy transferred:	220,797 kip-ft (299 MJ)
Noise Attenuation System (NAS)	
Two-tier unconfined bubble curtain airflow rate:	1400–1750 cubic feet minute (cfm), 60–66 pounds per square inch (psi)
River conditions during pile driving:	Ebb tide, 0.5–1.6 knots (0.25–0.8 meters per second [m/s] depth dependent; Table 6 and Figure 7)

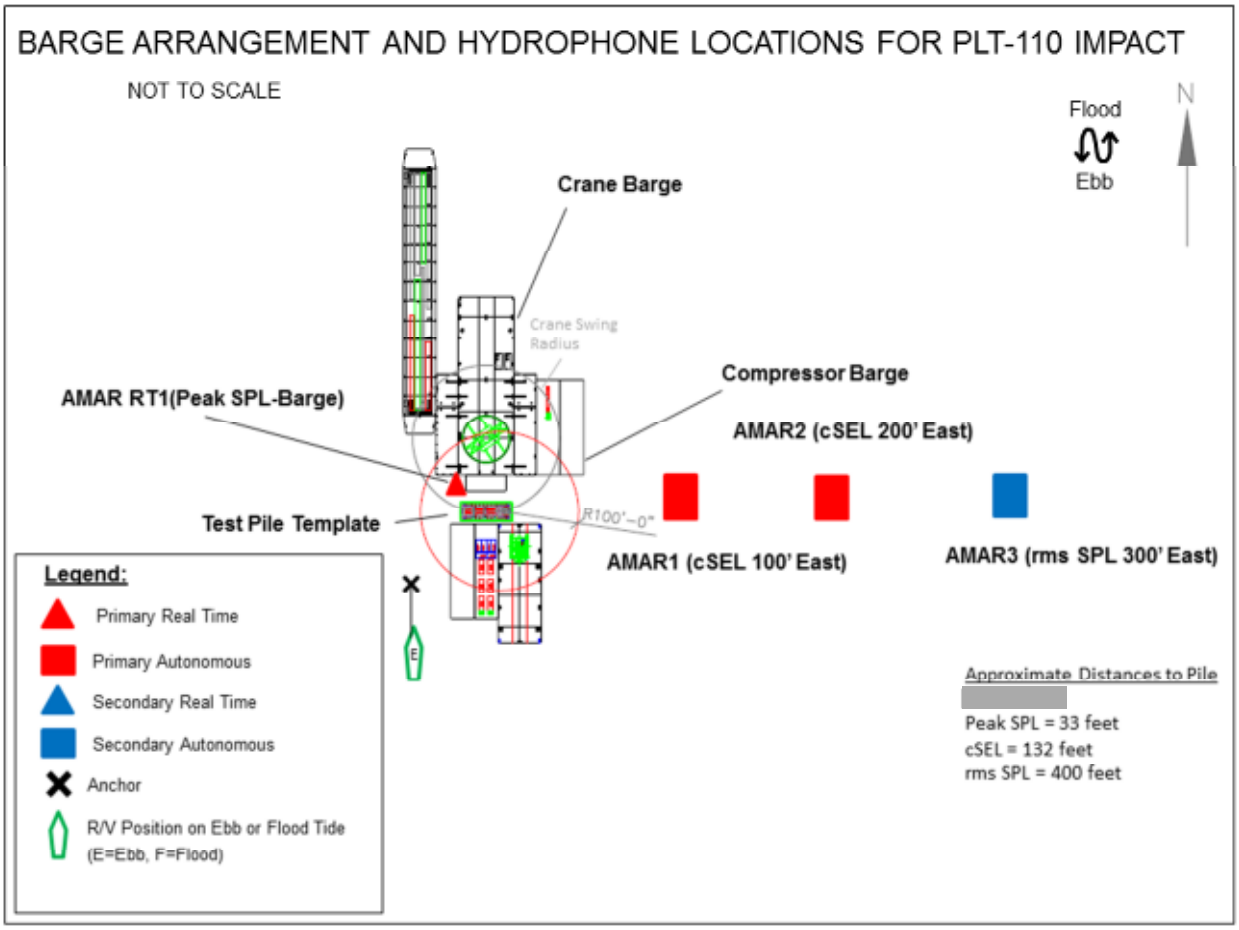

Figure 1. Plan view of pile and barge layout, 06 September 2013, PLT-110.

Table 2. Summary of Autonomous Multichannel Acoustic Recorders (AMAR) locations and measured sound levels. Detailed sound level plots are contained in Appendix A.

Location	Recorder ID	Distance to pile (ft)	Water depth (ft)	Max peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^{2}s*)
Peak SPL Barge (up current)	AMAR-RT-11	33	18	192	195
cSEL 100' East (cross current)	AMAR-175	132	18	177	180
cSEL 200' East (cross current)	AMAR-221	221	18	171	176
rms SPL 300' East (cross current)	AMAR-228	389	20	166	166

* Estimated at each recorder by multiplying the mean of the per-strike SEL by the number of strikes reported by the pile driving contractor, for the final value at the recorder, representing the total energy at the end of pile driving.

1.2. NMFS Physiological and Behavioral Thresholds

The distances from pile driving to the noise levels that serve as the National Marine Fisheries Service (NMFS) physiological and behavioral thresholds were extrapolated using a logarithmic regression based on mean values of the peak sound pressure level (SPL), root-mean-square (rms) SPL, and SELss from each recorder (Table 3 and Figure 2).

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was approximately 13 ft, and did not exceed NMFS criteria of a diameter of 40 ft for [redacted] piles. The diameter of the 187 dB re 1 $\mu Pa^2 \cdot s$ cumulative sound exposure level (cSEL) isopleth was estimated to be 140 ft at the end of pile driving. Since cSEL increases as the number of strikes increases, the diameter of the 187 dB isopleth was smaller than 140 ft for most of the pile driving operation. No other pile driving occurred during this pile load test. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

Table 3. Estimated isopleth diameters for the NMFS physiological and behavioral thresholds.

Criteria	Estimated diameter (ft)
206 dB re 1 µPa peak SPL	13
187 dB re 1 $\mu Pa^2 \cdot s$ cSEL*	140
150 dB re 1 µPa rms SPL (1 s integration time)	572

* At the end of pile driving

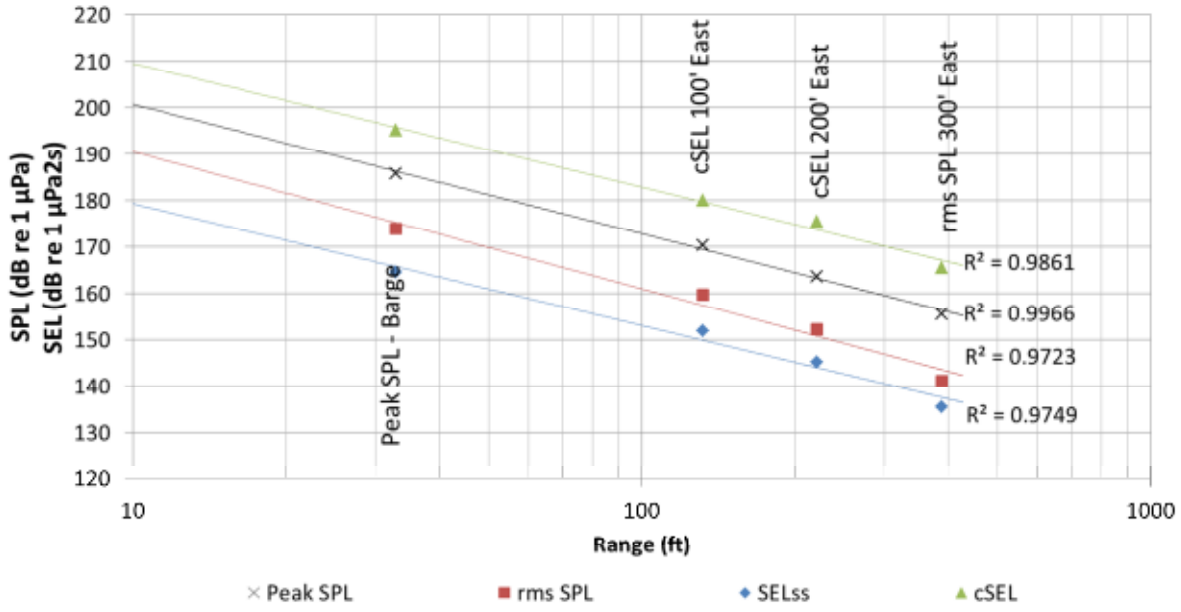

Figure 2. Regression based on mean values of the SELss, peak SPL, cSEL, and rms SPL from each recorder from pile driving of Test Pile PLT-110, 06 September 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents total sound energy measured during the pile driving.

1.3. Observations

The recorder at location cSEL 100' East (AMAR-175) was dragged by a tug boat at 16:40 EDT. After that time its position was no longer certain, so data are not included for AMAR-175 after that point. There was a brief period (16:24:37–16:25:19) of pile driving that occurred without the NAS operating. During this period, peak SPL levels of 206 dB re 1 µPa were measured at location Peak SPL Barge (Figure 8) and SELss increased by 10–15 dB at each measurement location (Figure 3). The estimated diameter the 206 dB re 1 µPa peak SPL isopleth using only the 15 strikes that occurred without the NAS was 41 feet for approximately 12 seconds (Figure 4).

The hammer energy during pile driving at PLT-110 varied from 125–280 kip-ft (Figure 3, Figure 5). The NAS air pressure and airflow were nearly constant at 60–65 psi and 1400–1750 cfm (Figure 3, Table 5). Pile driving occurred during the ebb tide, with an approximate average current of 0.5 to 1.6 knots (Figure 3, Figure 7); however, the only observable effect on the measured sound occurred when the NAS was temporarily turned off (Figure 3).

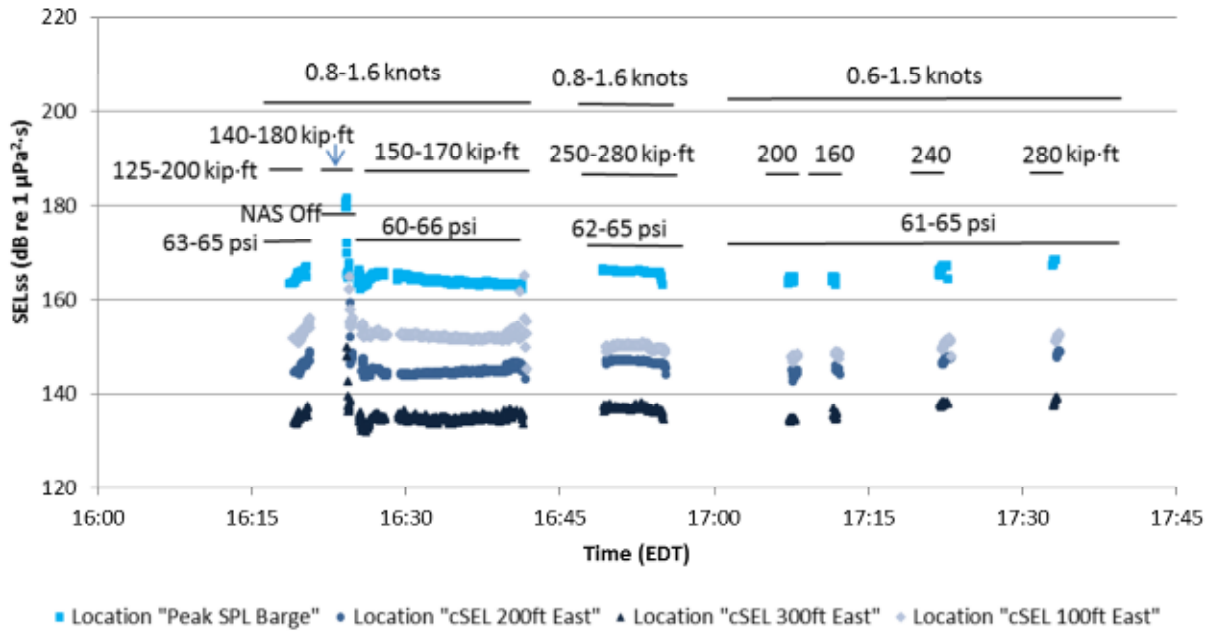

Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

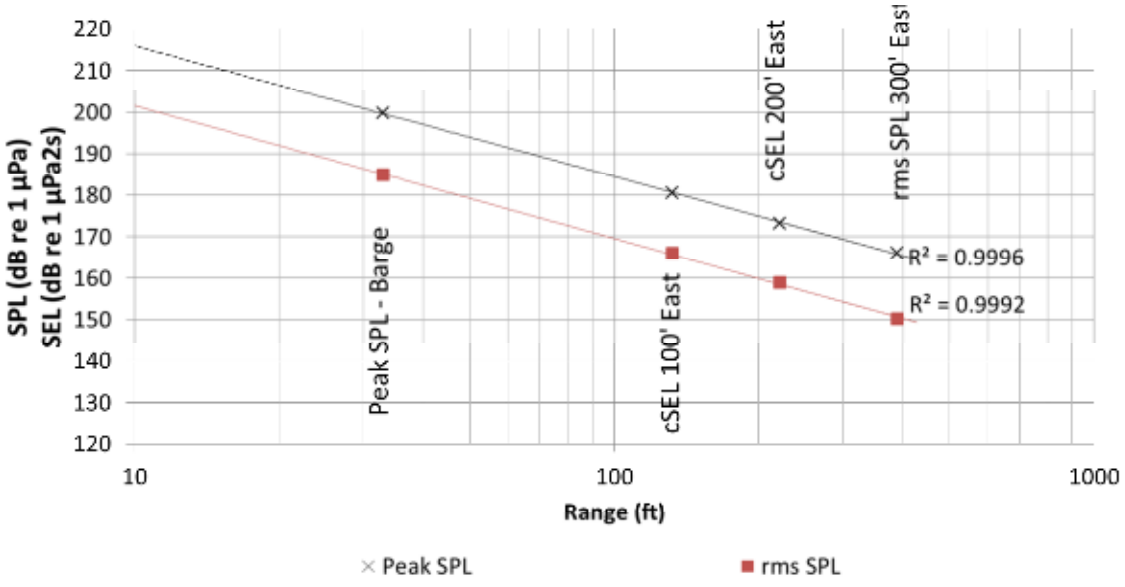

Figure 4. Regression based on mean values of the peak SPL and rms SPL from each recorder from pile driving of Test Pile PLT-110, 06 September 2013 for the 15 strikes (for approximately 12 seconds) when the NAS was disabled. peak SPL, and rms SPL are instantaneous values.

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 06 September 2013.

Table 4. JASCO and construction activities for Test Pile PLT-110, 06 September 2013.

Time (EDT)	Activity
08:45	Arrive at Cornetta's, prep gear
09:30	Transit to job site
10:10	Begin deploying AMAR-221, AMAR-175, and AMAR-228
10:25	Transit to Hudson Harbor to standby
12:00	Transit to Cornetta's
13:15	Transit to Hudson Harbor to transfer to barge
13:30	Prepare AMAR-RT-11
14:00	Stand by
14:42	Deploy AMAR-RT-11; start crane picking hammer
16:19	Start pile driving
16:40	AMAR-175 dragged by a tugboat
17:34	Stop pile driving
17:45	Retrieve AMAR-RT-11
18:30	Retrieve AMAR-221, AMAR-175 and AMAR-228
18:45	All work complete

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Two-tier unconfined bubble curtain

NAS settings: 1400–1750 cfm, 60–66 psi

Table 5. NAS setting recorded during pile driving at Test Pile PLT-110, 06 September 2013.

Time (EDT)	Volume/min (cfm)	Pressure (psi)
16:19–16:21	1400–1650	63–65
16:24–16:28	1500–1700	60–65
16:29–16:41	1400–1750	60–66
16:49–16:55	1400–1650	62–65
17:07–17:09	1400–1650	62–65
17:12	1700–1650	62–65
17:22–17:23	1450–1700	61–65
17:33	1450–1700	61–65

2.2.2. Impact Hammering Log

Total energy: 220,797 kip-ft (299 MJ)

Total number of strikes: [redacted]

Maximum per-strike energy: 283.3 kip-ft (384 kJ)

Net pile driving duration (hh:mm:ss): 00:25:11

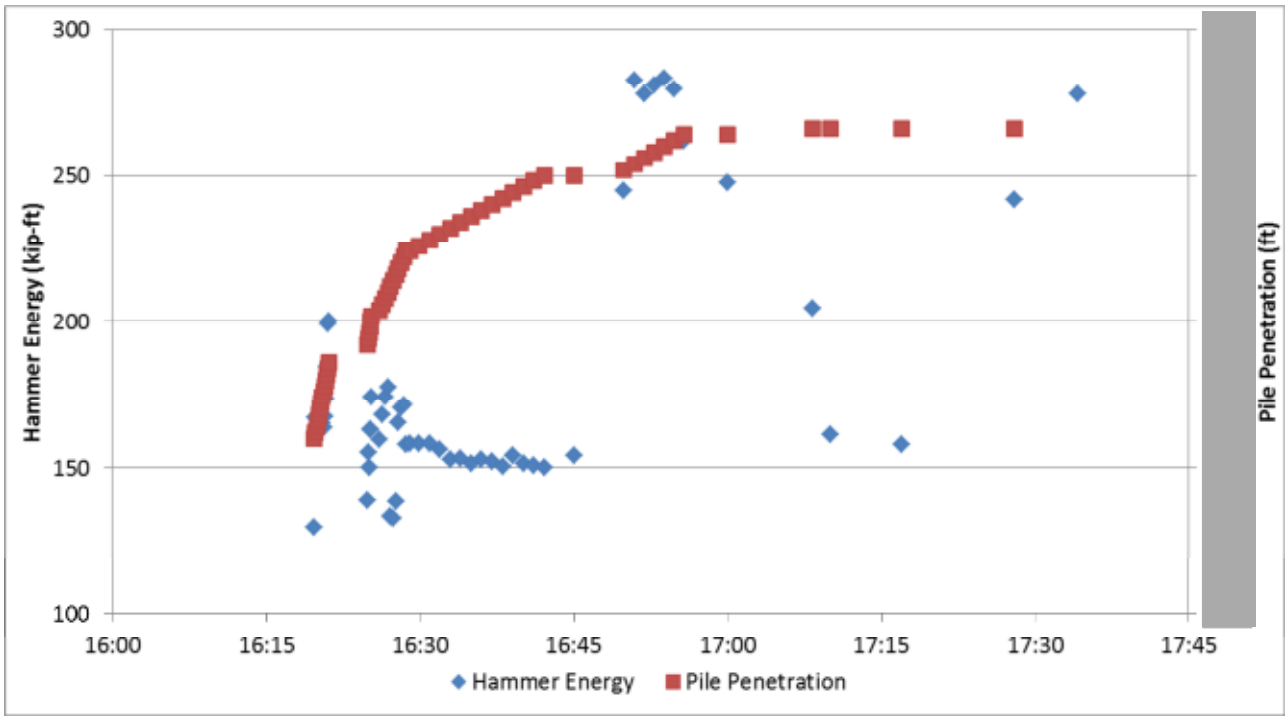

Figure 5. Hammer energy (kip-ft) and pile penetration (ft) for the impact pile driving of PLT-110 on 06 September 2013.

3. Weather and River Conditions

Table 6 provides the predicted currents at the project site for 06 September 2013. Figure 6 provides the measured speed of sound in water, based on a conductivity, temperature, depth (CTD) cast. Figure 6 provides the measured currents at the project site on 06 September 2013 using an Acoustic Doppler Current Profiler (ADCP).

Table 6. Weather conditions, and predicted local current times (EDT).

Weather conditions:	Sunny, ~ 3 knots northerly wind
Full ebb current:	17:13 (2.2 knots)
Slack current:	13:41, 20:06
Full flood current:	10:38 (1.2 knots)

Reference: http://tidesandcurrents.noaa.gov/get_predc.shtml?year=2013&stn=0611+George WashingtonBridge&secstn=Tappan+Zee+Bridge&sbfh=%2B1&sbfm=12&fldh=%2B0&fldm=55&sbeh=%2B0&sbem=52&ebbh=%2B1&ebbm=06&fldr=0.6&ebbr=0.8&fldavgd=356&ebbavgd=175&footnote=

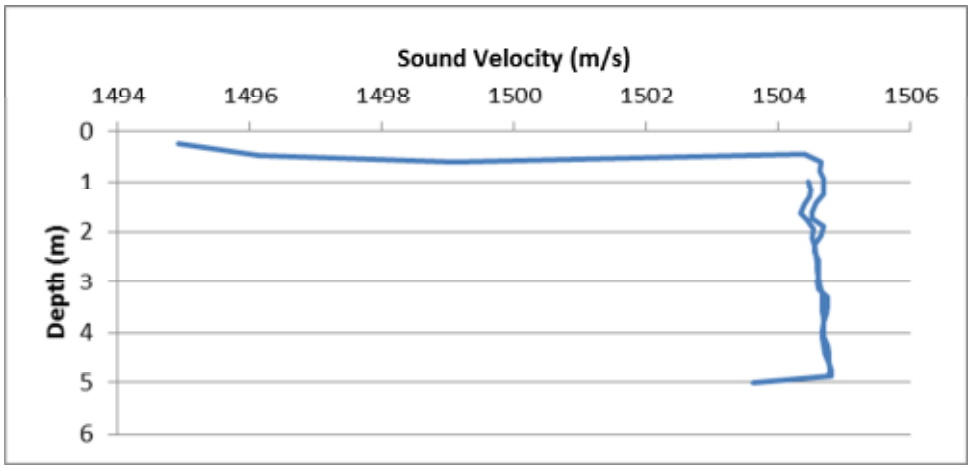

Figure 6. CTD cast performed at 14:22 (EDT) from the Alpine vessel, located 264 ft SE of the pile (41.07079 N, 73.8917 W).

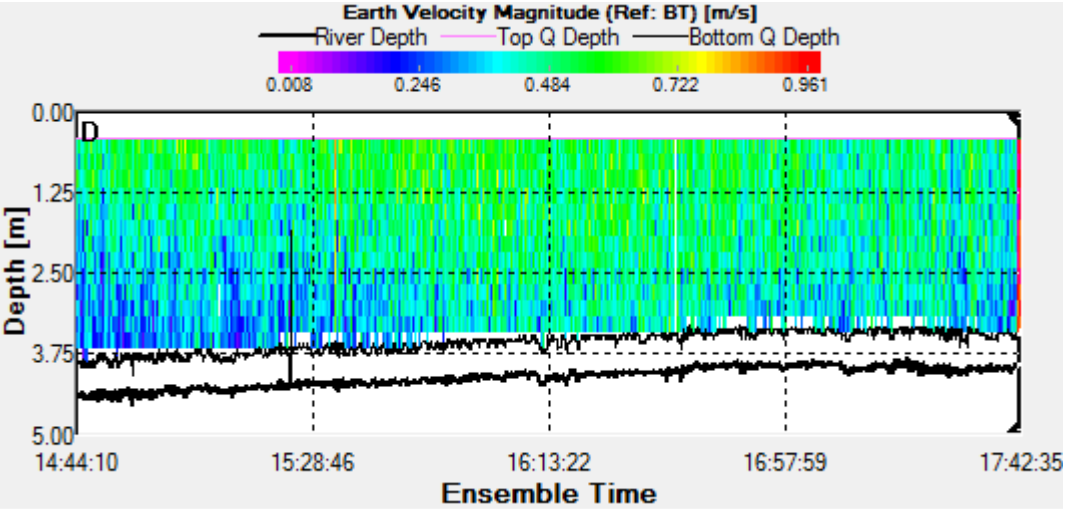

Figure 7. ADCP data from 06 September from the Alpine vessel, located 264 ft SE of the pile (41.07079 N, 73.8917 W), times are in EDT.

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 7 provides information on the real-time monitoring equipment used on 06 September 2013.

Table 8 provides location information on the real-time recorders.

Table 7. Real-time monitoring equipment for Test Pile PLT-110, 06 September 2013.

Equipment used		Units deployed
Acoustic Data Logger		
Model:	AMAR RT (JASCO Applied Sciences)	1
SpectroPlotter version:	6.0.1	1
Hydrophone		
Model:	M8KC (GTI)	1
AMAR-RT-11 sensitivity:	−210.8 dB re 1 V/µPa	1
Other		
Hydrophone calibrator:	Pistonphone Type 42AC (G.R.A.S. Sound and Vibration)	1
CTD profiler:	Minos X (AML Oceanographic)	1
ADCP:	RDI Teledyne Workhorse Sentinel 1200 kHz	1

Table 8. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 06 September 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
Peak SPL Barge	AMAR-RT-11	41.07143	73.89115	14:42	18	33

4.2. Autonomous Monitoring Equipment

Table 9 provides information on the autonomous monitoring equipment used on 06 September 2013. Table 10 provides the locations of the autonomous recorders.

Table 9. Autonomous monitoring equipment for Test Pile PLT-110, 06 September 2013.

Equipment used		Units deployed
Acoustic Data Logger		
Model:	AMAR G3 (JASCO Applied Sciences)	3
SpectroPlotter version:	6.0.1	3
Hydrophone		
Model:	M8E-51-0dB (GTI)	3
AMAR-221 sensitivity:	−199.9 dB re 1 V/µPa	1
AMAR-228 sensitivity:	−200.1 dB re 1 V/µPa	1
AMAR-175 sensitivity:	−200.1 dB re 1 V/µPa	1

Table 10. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 06 September 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
cSEL 100’ East (cross current)	AMAR-175	41.07137	73.8906	10:10	18	132
cSEL 200’ East (cross current)	AMAR-221	41.07137	73.8903	10:14	18	221
rms SPL East (cross current)	AMAR-228	41.07135	73.8897	10:20	20	389

Appendix A. Pile Driving Plots

A.1. Impact Pile-Driving Sound Levels from Peak SPL Barge

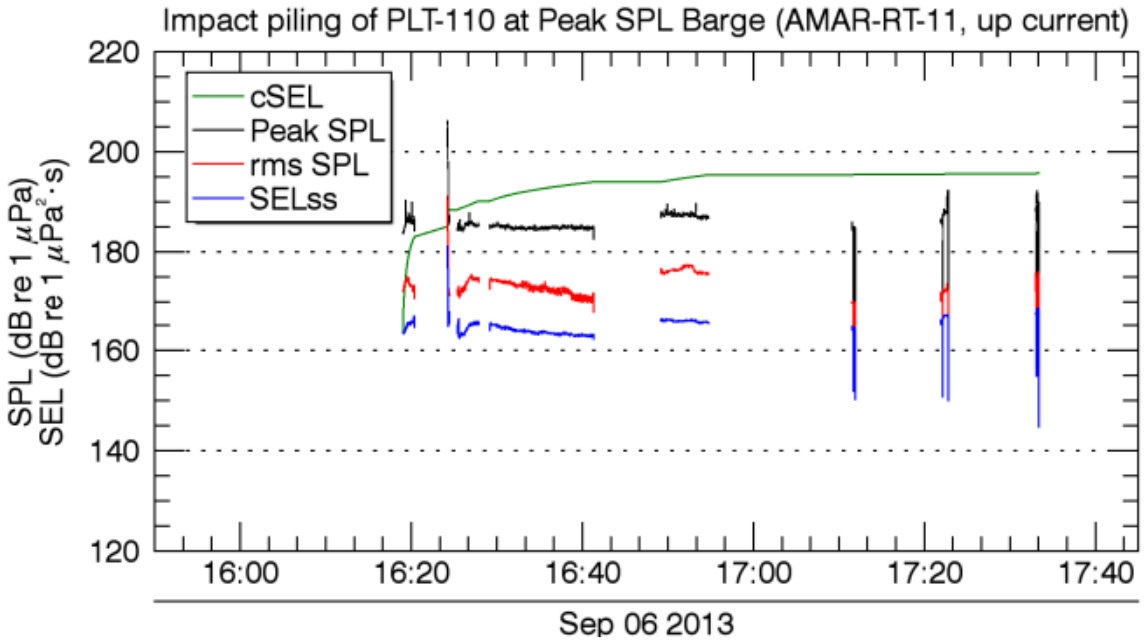

Figure 8. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-110 measured 33 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

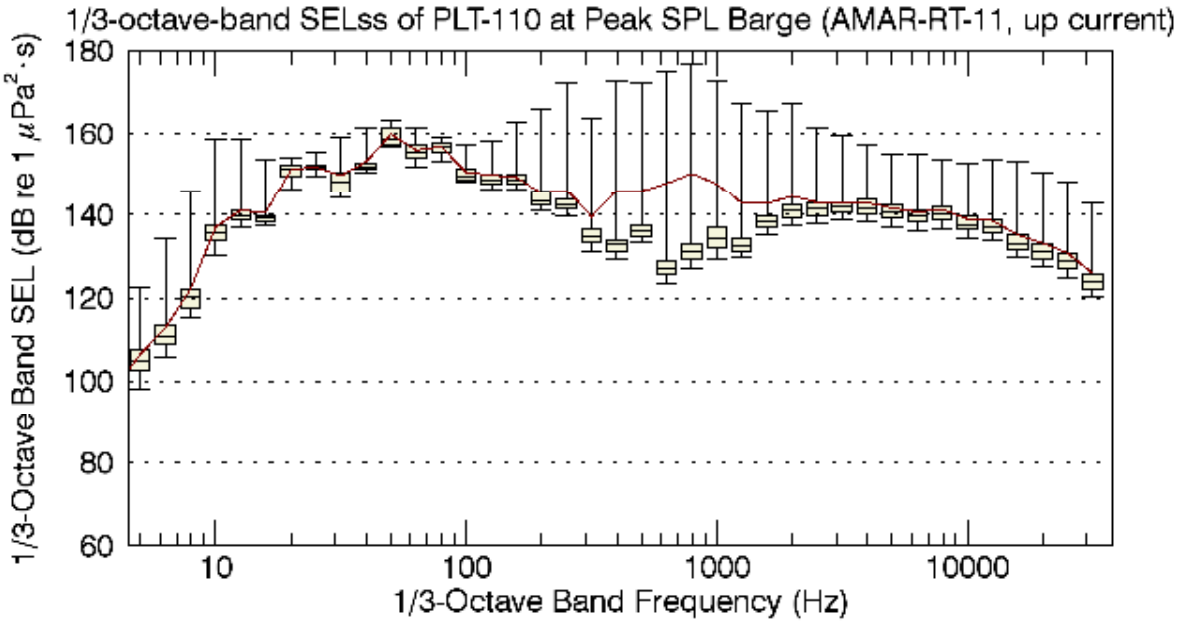

Figure 9. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-110 measured 33 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 11. Sound levels for the pile driving of Test Pile PLT-110 measured 33 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	192.4	177.3	168.4
L_5	187.8	176.7	166.1
L_{25}	186.7	174.6	165.6
L_{50}	185.1	173.3	164.2
L_{75}	184.7	172.0	163.3
L_{95}	184.4	170.1	162.9
L_{mean}	185.9	173.9	164.6

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.2. Impact Pile-Driving Sound Levels from cSEL 100' East

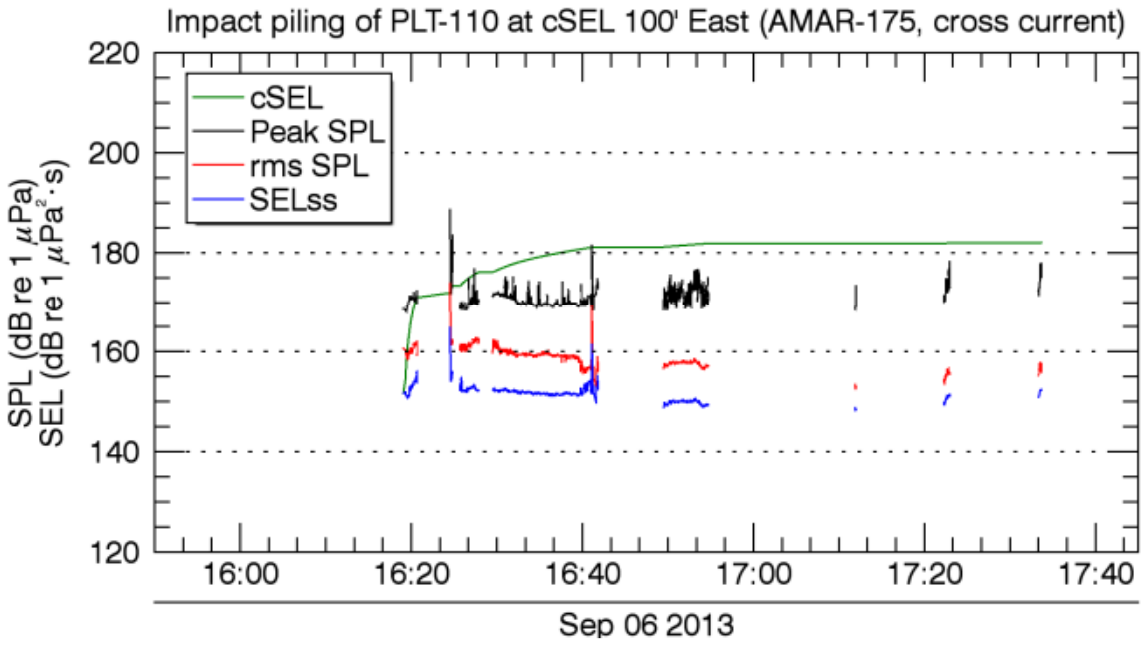

Figure 10. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-110 measured 132 ft from the pile at location cSEL 100' East using AMAR-175. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time. The sound spike at 16:41 was caused by a tugboat dragging the recorder. Data after this time was not used in the regressions or 1/3-octave-band plots since the range to the recorder was uncertain.

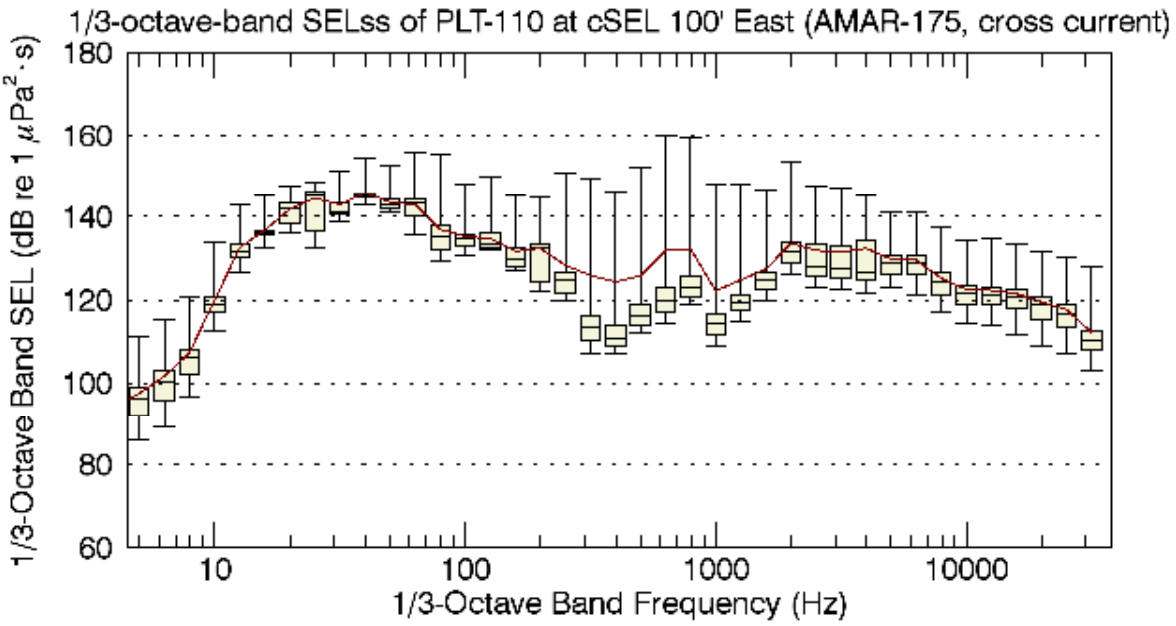

Figure 11. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-110 measured 132 ft from the pile at location cSEL 100' East using AMAR-175. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 12. Sound levels for the pile driving of Test Pile PLT-110 measured 132 ft from the pile at location cSEL 100' East using AMAR-175.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	176.9	162.6	154.3
L_5	172.2	161.8	152.9
L_{25}	170.8	160.2	152.2
L_{50}	169.7	159.4	151.7
L_{75}	169.4	159.1	151.5
L_{95}	169.0	158.5	151.3
L_{mean}	170.3	159.8	151.9

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.3. Impact Pile-Driving Sound Levels from cSEL 200' East

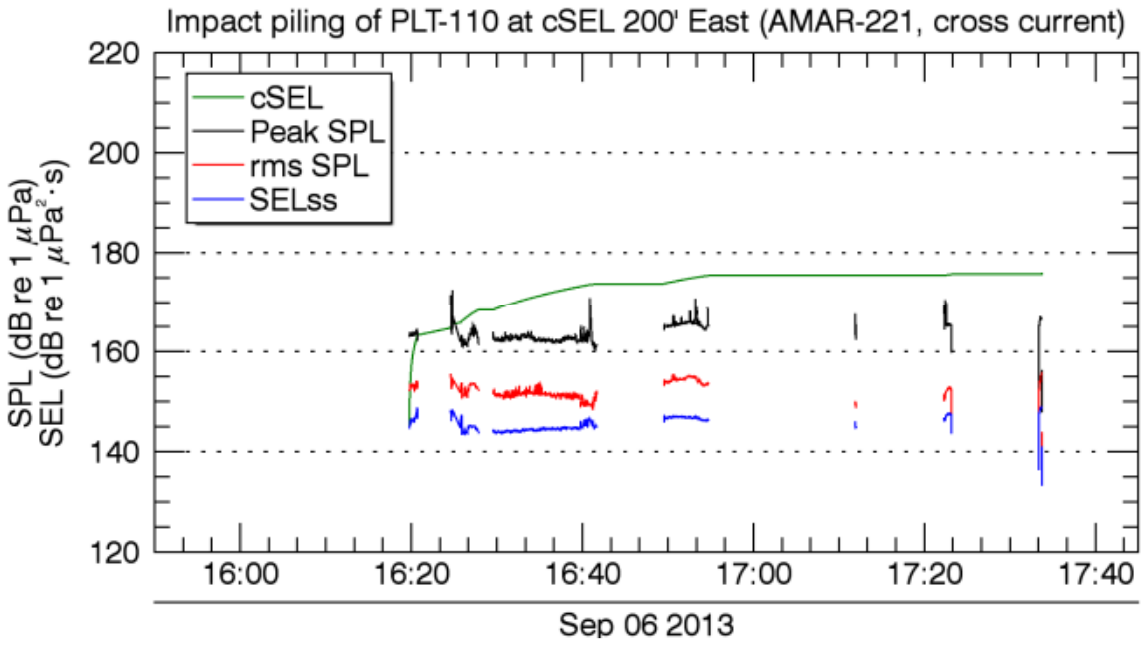

Figure 12. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-100 measured 221 ft from the pile at location cSEL 200' East using AMAR-221. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

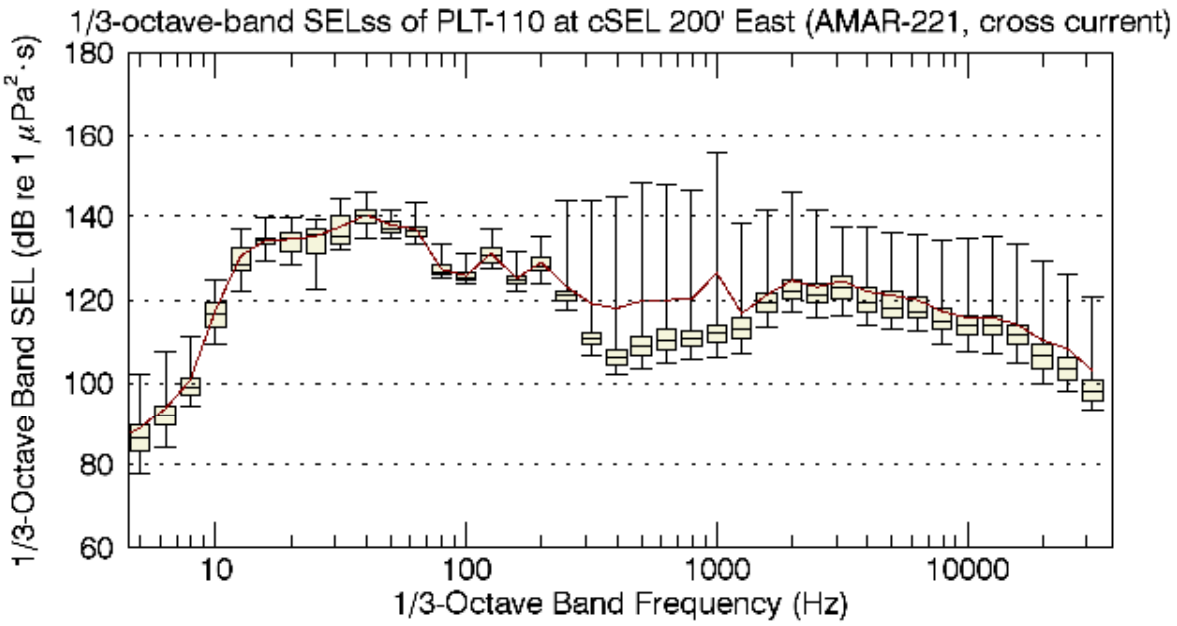

Figure 13. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-110 measured 221 ft from the pile at location cSEL 200' East using AMAR-221. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 13. Sound levels for the pile driving of Test Pile PLT-110 measured 221 ft from the pile at location cSEL 200' East using AMAR-221.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	170.9	155.7	148.9
L_5	166.0	154.9	147.0
L_{25}	164.8	153.4	146.3
L_{50}	162.8	151.6	144.7
L_{75}	162.2	151.1	144.3
L_{95}	161.3	149.5	143.8
L_{mean}	163.7	152.3	145.3

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.4. Impact Pile-Driving Sound Levels from rms SPL 300' East

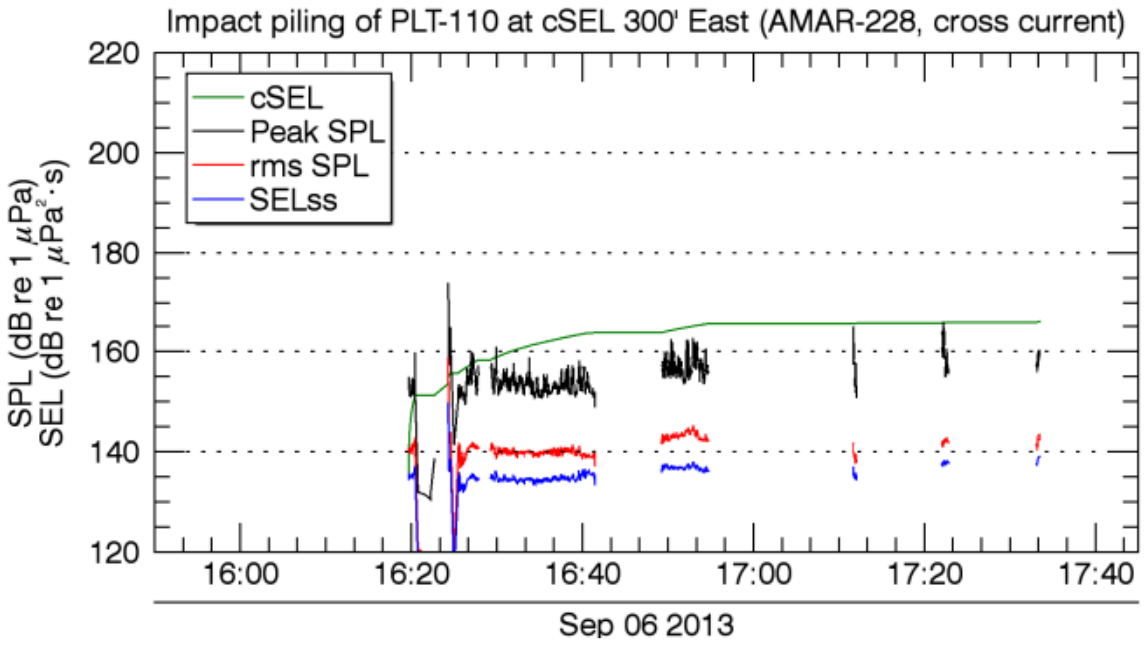

Figure 14. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-110 measured 389 ft from the pile at location rms SPL 300' East using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

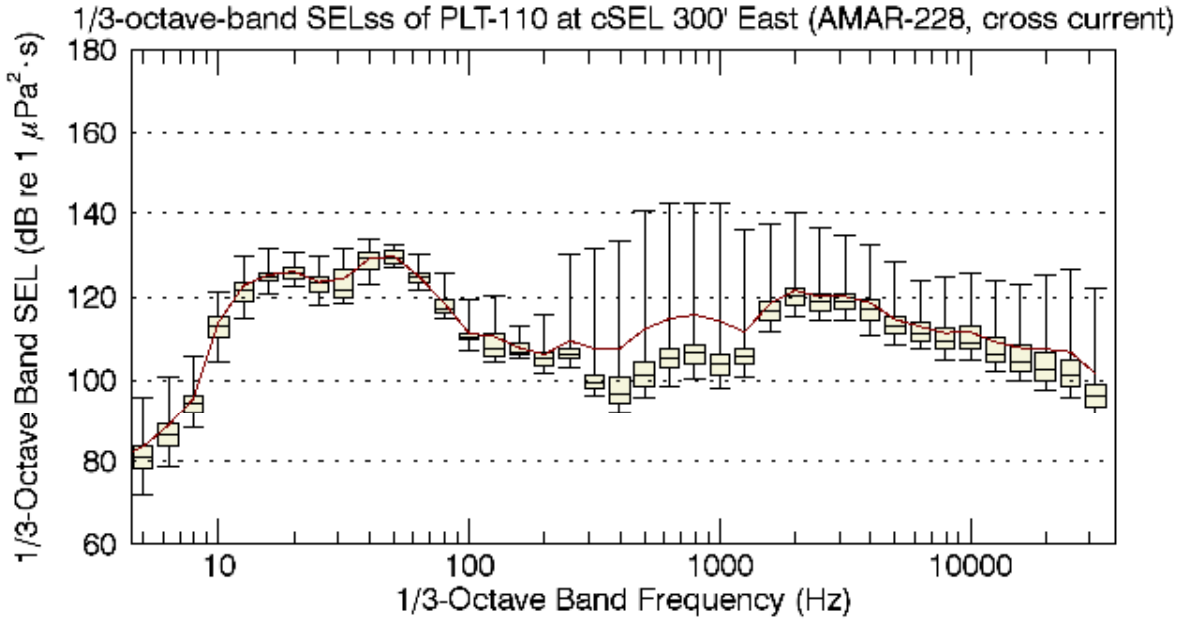

Figure 15. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-110 measured 389 ft from the pile at location rms SPL 300' East using AMAR-228. Beige bars indicate the first, second, and

third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 14. Sound levels for the pile driving of Test Pile PLT-110 measured 389 ft from the pile at location rms SPL 300' East using AMAR-228.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	166.0	145.2	139.2
L_5	160.0	143.8	137.4
L_{25}	156.0	142.2	136.4
L_{50}	153.9	140.2	134.9
L_{75}	152.5	139.7	134.4
L_{95}	151.2	139.0	133.9
L_{mean}	155.6	141.1	135.5

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the nth percentile level (L_n) is the SPL or SEL exceeded by n% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 112RE Installation

Daily Memorandum for 16 September 2013

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25 February 2014

P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-112RE is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 16 September 2013 (Table 1). One real-time acoustic monitoring system and two autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors, LLC (TZC) to measure sound levels at ranges of 34.3–581 ft from the pile (Figure 1, Table 2). Pile driving occurred between 13:50–14:20 Eastern Daylight Time (EDT), and full ebb current occurred at 14:02 EDT.

Table 2 provides the sound levels measured at each recorder. Plots of the measured values, frequency distributions of 1/3-octave-band single-strike sound exposure levels (SELss), and sound level statistics for the distribution of the measured data are presented in Appendix A.

Table 1. Summary of Test Pile PLT-112RE activities, 16 September 2013.

Date:	16 September 2013
Pile-Driving Activity	
Test pile identifier:	PLT-112RE
Pile diameter:	[redacted]
Water depth:	38 ft
Hammer type:	Impact (IHC S-800)
Total hammer strikes:	[redacted]
Total penetration:	[redacted]
Net duration of pile driving (hh:mm:ss):	00:15:19
Maximum single strike energy:	168.0 thousand foot-pounds (kip-ft), (227 kJ)
Total energy transferred:	135,539 kip-ft (184 MJ)
Noise Attenuation System (NAS)	
Five-tier unconfined bubble curtain airflow rate:	1250–1400 cubic feet per minute (cfm), 70 pounds per square inch (psi)
River conditions during pile driving:	Ebb current, 0.8-2.2 knots (0.4–1.1 meters per second [m/s] depth dependent; see Table 7, and Figure 8)

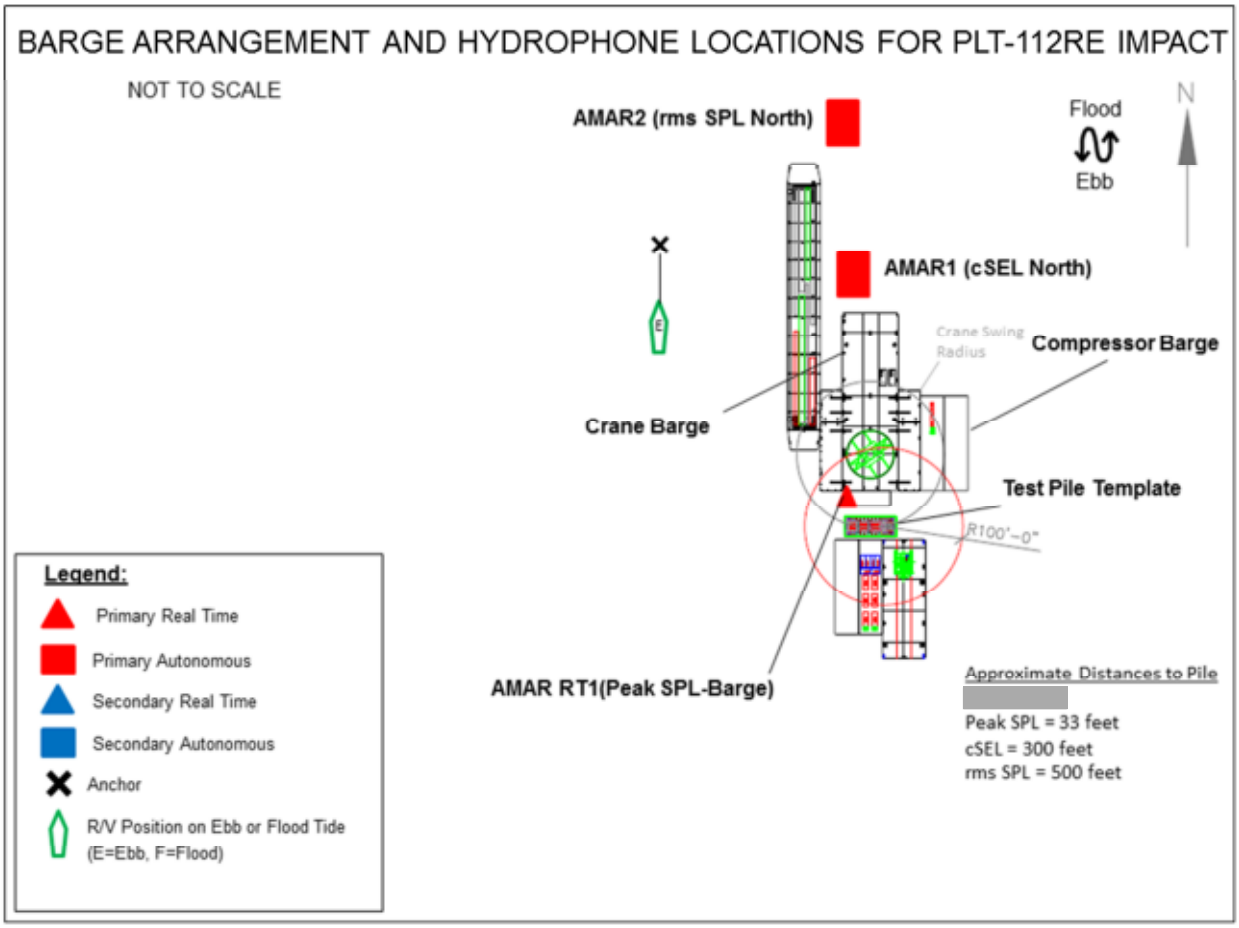


Figure 1. Plan view of pile and barge layout, 16 September 2013, Test Pile PLT-112RE.

Table 2. Summary of Autonomous Multichannel Acoustic Recorder (AMAR) locations and measured sound levels. Detailed sound level plots are contained in Appendix A.

Location	Recorder ID	Distance to pile (ft)	Water depth (ft)	Max peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^{2}s)*
Peak SPL Barge (up current)	AMAR-RT-11	34	38	202	197
cSEL North (up current)	AMAR-175	304	36	184	175
rms SPL North (up current)	AMAR-228	581	36	171	168

* At the end of pile driving

1.2. NMFS Physiological and Behavioral Thresholds

The distances from pile driving to the noise levels that serve as the National Marine Fisheries Service (NMFS) physiological and behavioral thresholds were extrapolated using a logarithmic regression based on mean values of the peak sound pressure levels (SPL), root mean square (rms) SPL, and SELss from each recorder (Table 3 and Figure 2).

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was approximately 16 ft, and did not exceed NMFS criteria of a diameter of 100 ft for [redacted] piles. The diameter of the 187 dB re 1 μPa^2•s cumulative sound exposure level (cSEL) isopleth was estimated to be 184 ft at the end of pile driving. Since cSEL increases as the number of strikes increases, the diameter of the 187 dB isopleth was smaller than 184 ft for most of the pile driving operation. No other pile driving occurred during this pile load test. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

Table 3. Estimated isopleth diameters for the NMFS physiological and behavioral thresholds.

Criteria	Estimated mean Diameter (ft)
206 dB re 1 µPa peak SPL	16
187 dB re 1 μPa^2·s cSEL*	184
150 dB re 1 µPa rms SPL (1 s integration time)	784

* At the end of pile driving

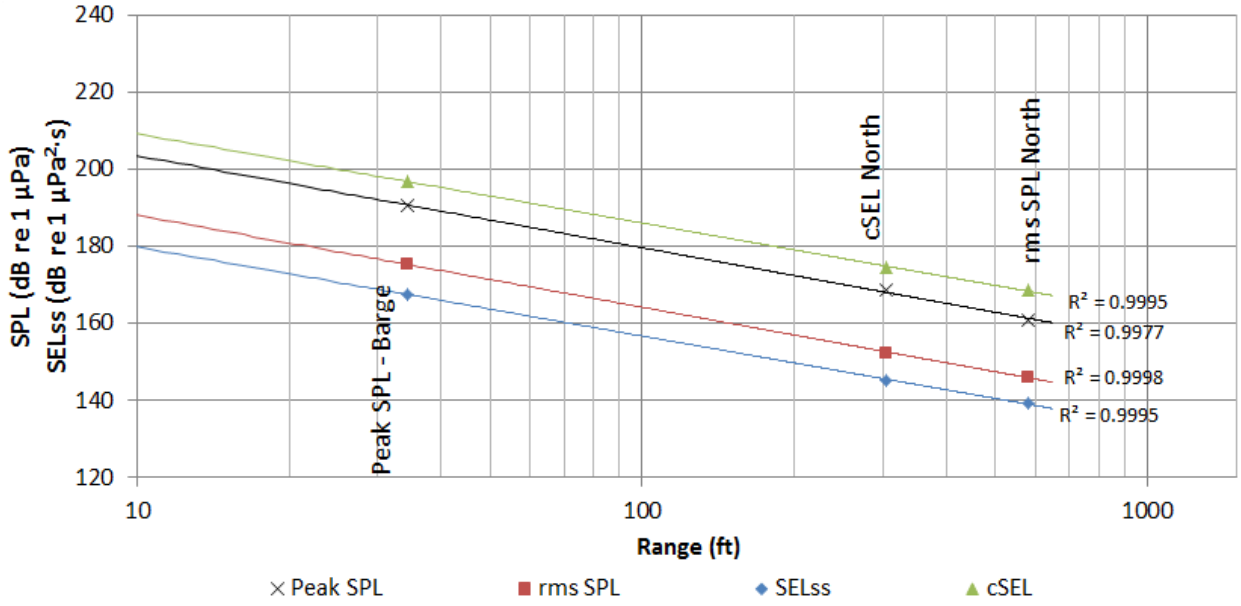


Figure 2. Regression based on mean values of the SELss, peak SPL, cSEL, and rms SPL from each recorder from pile driving of Test Pile PLT-112RE, 16 September 2013. SEL_{ss}, peak SPL, and rms SPL are the mean instantaneous values. The cSEL represents the total sound energy measured during the pile driving.

1.3. Observations

Acoustic measurements at PLT-112RE were made along a radial up current from the pile during full ebb current in deep water. Currents were measured by the ADCP to be in excess of 2 knots at the surface and 0.8 - 1.0 knots at the river bottom (Figure 8). The NAS system was operated at 70 psi (1250-1400 cfm) during the piling of PLT-112RE (Figure 3, Table 6). The hammer was operated at a hammer energy of 150+/-10 kip-ft for most of the pile (Figure 3, Figure 6). The pile penetrated the substrate at a continuous rate from 13:52–14:05, then hit refusal (Figure 4, Figure 6). Over the 13 minute period before refusal (13:52-14:05) peak SPL, rms SPL and SELss decreased at each recorder by 6-15 dB (Figure 3, Figure 9, Figure 11, Figure 13). Pile driving continued sporadically from 14:05 to about 14:23 at slightly increased hammer energies however the pile only penetrated three more feet and sound levels increased slightly (Figure 4, Figure 6).

Figure 3 compares the pile penetration and hammer energy with the measured sound levels for each location Peak SPL Barge. Over the period of 13:52-14:05 the sound levels appear to be negatively correlated with pile penetration. From 14:05-14:23 the hammer energy and sound levels appear to increase slightly.

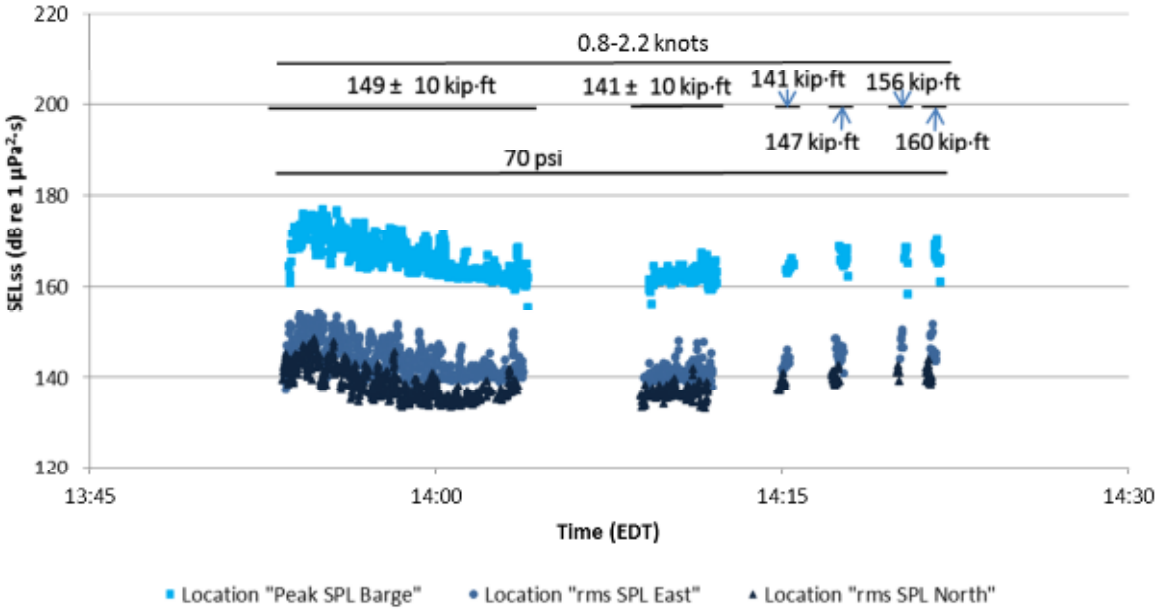


Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

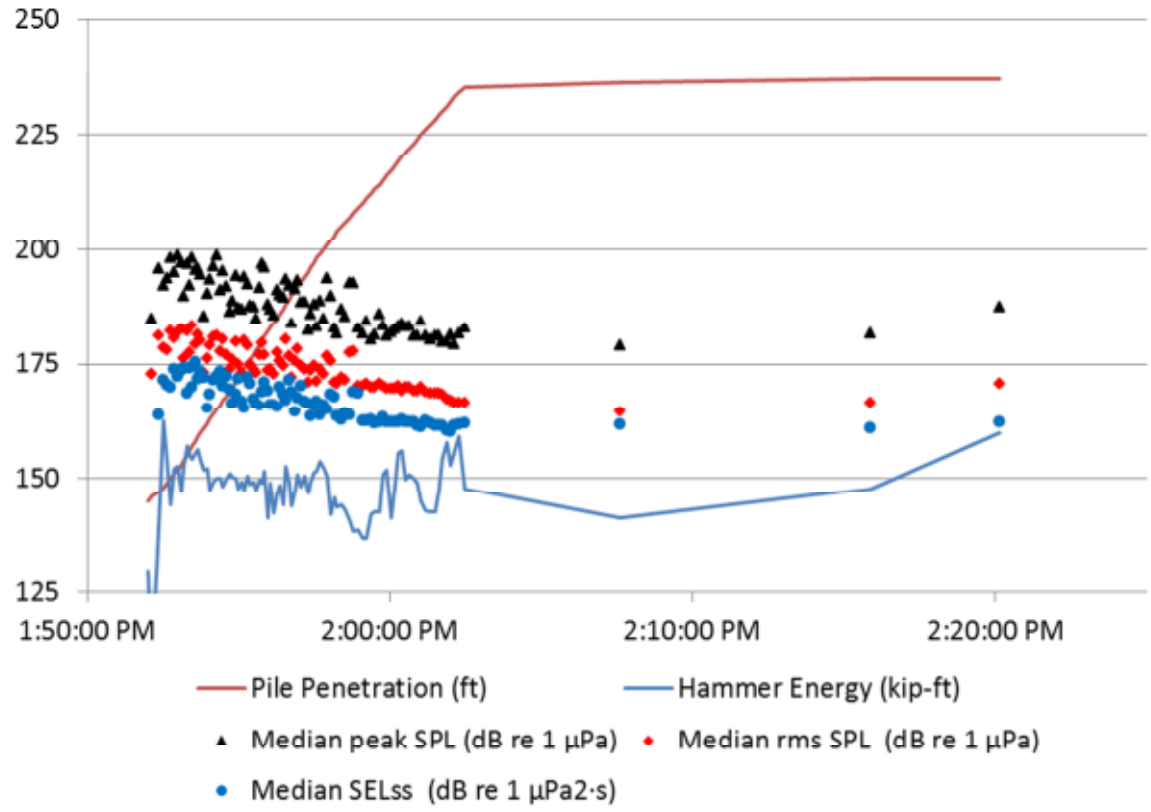


Figure 4. Median measured peak SPL, rms SPL and single strike SEL for each foot of penetration of PLT-112RE, compared to the pile penetration (ft) and the median hammer energy (kip-ft).

A regression using only the highest mean sound levels measured from 13:52–13:54 showed that the isopleths for the NMFS criteria remained well within the permitted values (Figure 5,Table 4).

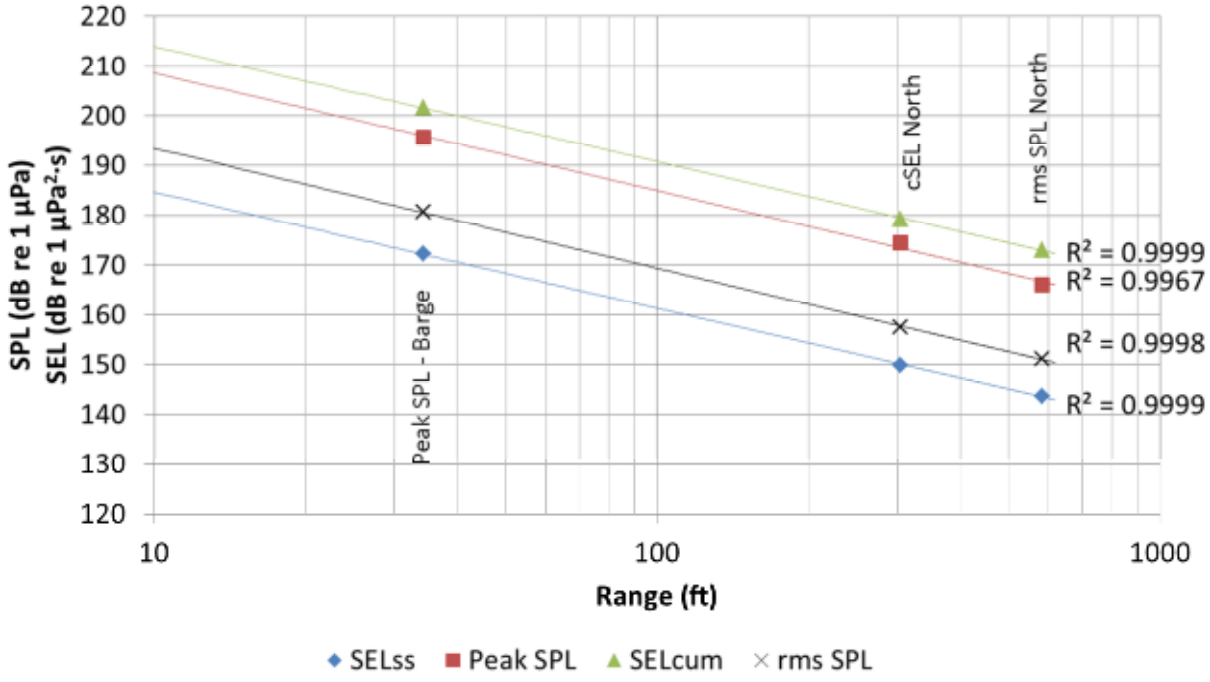


Figure 5. Regression based on mean values of the peak SPL, rms SPL, and single strike SELs from each recorder from pile driving of Test Pile PLT-112RE over the time range of 13:52-13:54 16 September 2013. SEL_{ss}, peak SPL, and rms SPL are the mean instantaneous values. The cSEL represents the total sound energy measured during the pile driving

Table 4. Estimated isopleth radii for the NMFS physiological and behavioral thresholds using only the sound levels measured from 13:52–13:54, the period with the highest mean sound levels measured.

Criteria	Estimated mean radius (ft)
206 dB re 1 µPa peak SPL	13
187 dB re 1 $\mu Pa^2 \cdot s$ cSEL*	145
150 dB re 1 µPa rms SPL (1 s integration time)	639

* At the end of pile driving assuming 879 strikes.

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 5 provides activities for 16 September 2013.

Table 5. JASCO and construction activities for Test Pile PLT-112RE, 16 September 2013.

Time (EDT)	Activity
08:00	Arrive at dock, prep recorders
08:45	Leave dock for job site
09:15	Transfer to barge to discuss deployment plans with foreman
09:30	Deploy AMAR-175 north of the barge spread, secure to barge
09:45	Transfer to barge
10:50	Deploy AMAR-RT-11
12:50	Start picking hammer
12:57	Deploy AMAR-228 at location rms SPL North from Alpine Vessel
13:13	Deploy AMAR-175 at location cSEL North from Alpine Vessel
13:52	Start pile driving
14:20	Stop pile driving
15:22	Retrieve and download data
16:45	Operations complete

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Five-tier unconfined bubble curtain

NAS Settings: 1250–1400 cfm, 70 psi

Table 6. NAS setting recorded during pile driving at Test Pile PLT-112RE, 16 September 2013.

Time (EDT)	Volume/min (cfm)	Pressure (psi)
13:53	1250–1400	70
14:20	1250–1400	70

2.2.2. Impact Hammering Log

Total energy: 135,539 kip-ft (184 MJ)

Total number of strikes: 879

Maximum per-strike energy: 168.0 kip-ft (227 kJ)

Net pile driving duration (hh:mm:ss): 00:15:19

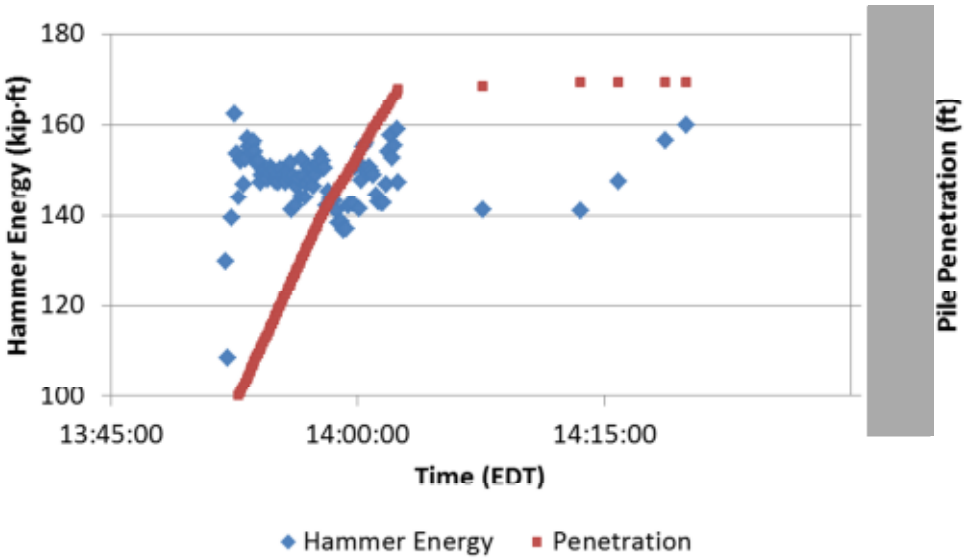


Figure 6.Hammer energy (kip-ft) and pile penetration (ft) during pile driving of PLT-112RE, 16 September 2013.

3. Weather and River Conditions

Table 7 provides the predicted currents at the project site on 16 September 2013. Figure 7 provides the speed of sound in water, based on salinity and temperature, measured using the conductivity, temperature, depth (CTD) cast. Figure 8 provides the measured currents at the project site on 16 September using an Acoustic Doppler Current Profiler (ADCP).

Table 7. Weather conditions, current, and predicted local tide times (EDT).

Weather conditions:	Sunny, ~ 3 knot northerly wind
Full ebb current:	14:02 (2.1 knots)
Slack current:	10:15, 16:45
Full flood current:	N/A

Reference: http://tidesandcurrents.noaa.gov/get_predc.shtml?year=2013&stn=0611+George Washington Bridge&secstn=Tappan+Zee+Bridge&sbfh=%2B1&sbfm=12&fldh=%2B0&fldm=55&sbeh=%2B0&sbem=52&ebbh=%2B1&ebbm=06&fldr=0.6&ebbr=0.8&fldavgd=356&ebbavgd=175&footnote=

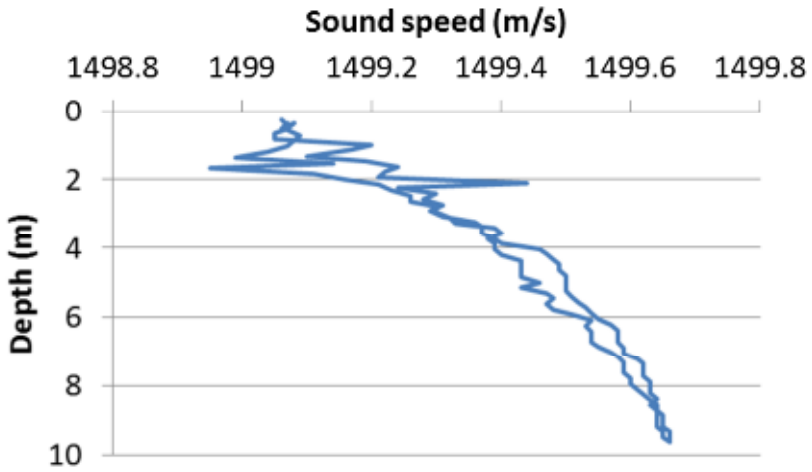


Figure 7. CTD cast performed at 13:56 EDT from the Alpine vessel , located 581 ft north of the pile (41.07417 N, 73.91453 W).

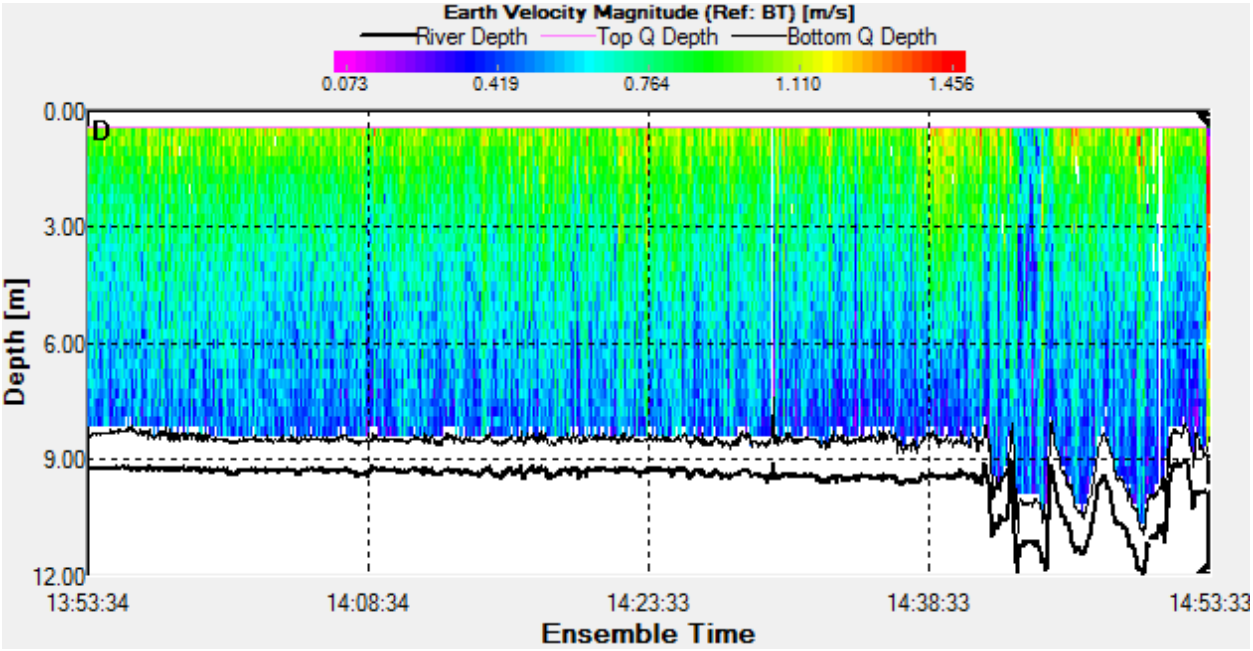


Figure 8. Current data measured by ADCP on 16 September 2013 from the Alpine vessel, located 581 ft north of the pile (41.07417 N, 73.91453 W), times are in EDT.

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 8 provides information on the real-time monitoring equipment used on 16 September 2013.

Table 9 provides location information on the real-time recorders.

Table 8. Real-time monitoring equipment for Test Pile PLT-112RE, 16 September 2013.

Equipment used		Units deployed
Acoustic data logger		
Model:	AMAR RT (JASCO Applied Sciences)	1
SpectroPlotter version:	6.0.1	1
Hydrophone		
Model:	M8KC (GTI)	1
AMAR-RT-11 sensitivity:	−210.9 dB re 1 V/µPa	1
Other		
Hydrophone calibrator:	Pistonphone Type 42AC (G.R.A.S. Sound and Vibration)	1
CTD profiler:	Minos X (AML Oceanographic)	1
ADCP:	RDI Teledyne Workhorse Sentinel 1200 kHz	1

Table 9. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 16 September 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
Peak SPL Barge (up current)	AMAR-RT-11	41.07143	73.87857	10:50	38	34.3

4.2. Autonomous Monitoring Equipment

Table 10 provides information about the autonomous monitoring equipment used on 16 September 2013. Table 11 provides the locations of the autonomous recorders.

Table 10. Autonomous monitoring equipment for Test Pile PLT-112RE, 16 16September 2013.

Equipment used		Units deployed
Acoustic data logger		
Model:	AMAR G3 (JASCO Applied Sciences)	2
SpectroPlotter version:	6.0.1	2
Hydrophone		
Model:	M8E-51-0dB (GTI)	2
AMAR-221 sensitivity:	−199.9 dB re 1 V/µPa	1
AMAR-228 sensitivity:	−200.1 dB re 1 V/µPa	1
AMAR-175 sensitivity:	−200.1 dB re 1 V/µPa	1

Table 11. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 16 September 2013

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
rms SPL North (up current)	AMAR-228	41.07294	-73.8785	12:57	36	581
cSEL North (up current)	AMAR-175	41.07217	-73.87866	13:13	36	304

Appendix A. Pile Driving Plots

A.1. Impact Pile-Driving Sound Levels from Peak SPL Barge

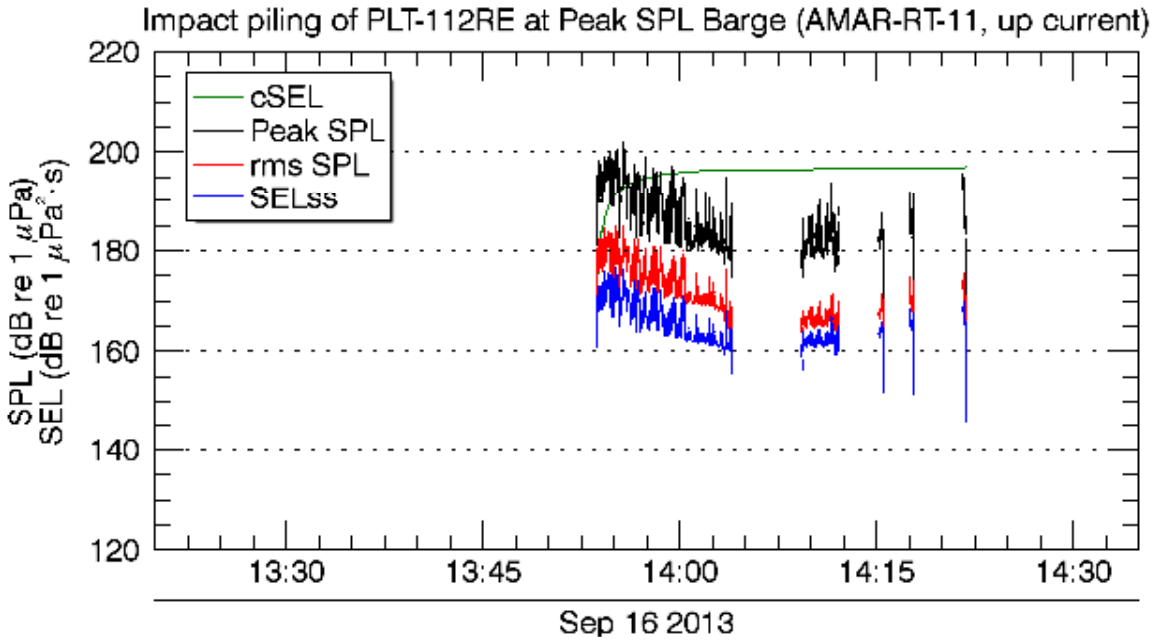


Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112RE measured 34.3 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

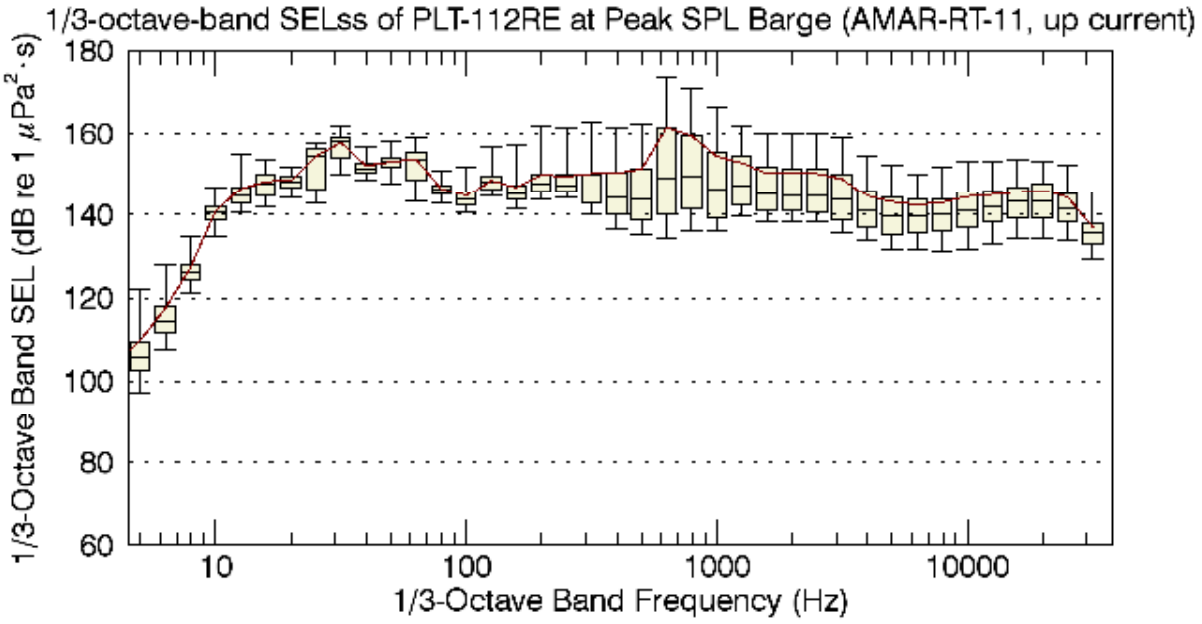


Figure 10. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112RE measured 34.3 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 12. Sound levels for the pile driving of Test Pile PLT-112RE measured 34.3 ft from pile at location Peak SPL Barge using AMAR-RT-11.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa²·s)
L_{max}	202.0	184.9	176.8
L_5	197.0	181.4	173.3
L_{25}	191.1	176.0	168.4
L_{50}	185.0	171.0	164.1
L_{75}	181.4	168.6	162.2
L_{95}	179.0	165.2	160.8
L_{mean}	190.6	175.4	167.6

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.2. Impact Pile-Driving Sound Levels cSEL North

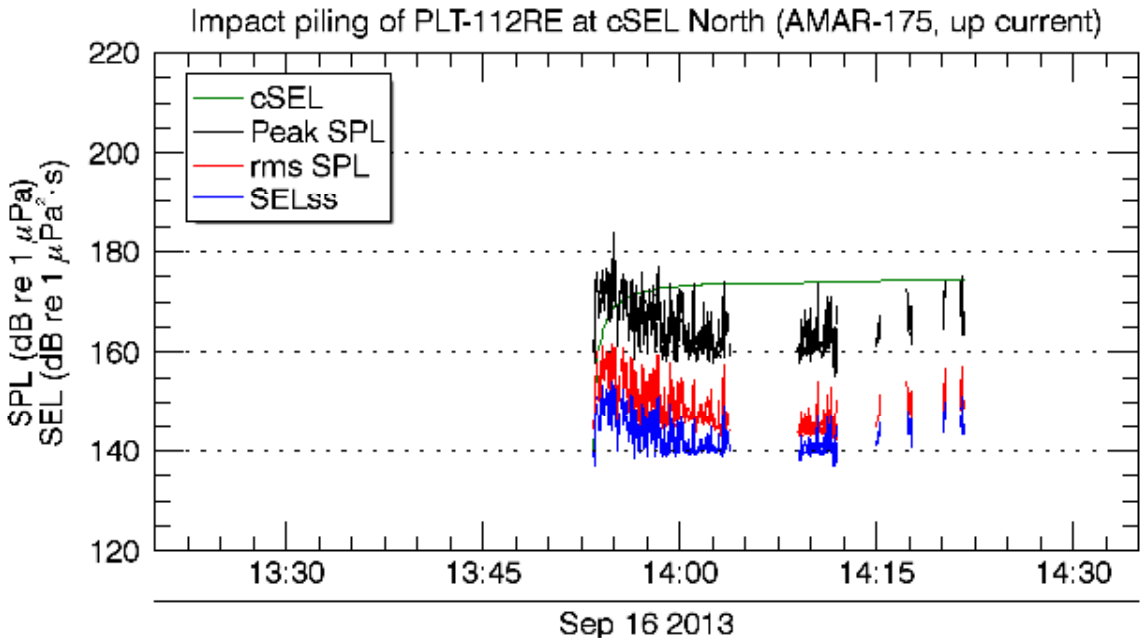


Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112RE measured 304 ft from the pile at location cSEL North using AMAR-175. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

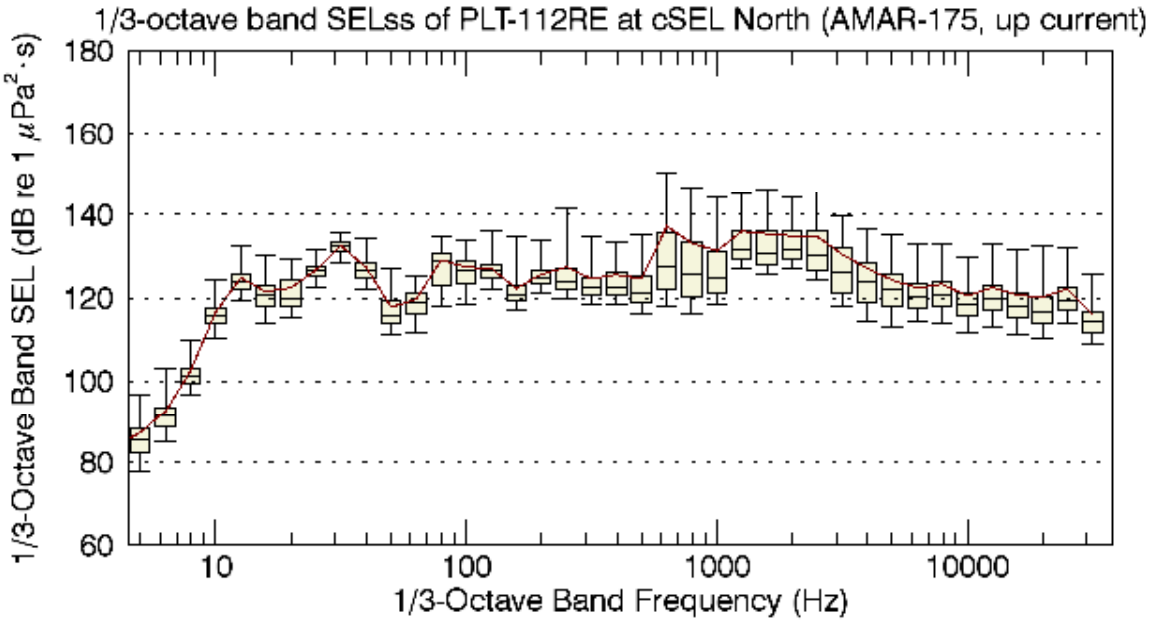


Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-112RE measured 304 ft from the pile at location cSEL North using AMAR-175. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 13. Sound levels for the pile driving of Test Pile PLT-112RE measured 304 ft from pile at location cSEL North using AMAR-175.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa²·s)
L_{max}	183.9	161.8	154.2
L_5	174.7	158.5	151.0
L_{25}	169.4	153.0	145.9
L_{50}	164.5	148.3	142.1
L_{75}	161.4	145.9	140.1
L_{95}	159.2	143.6	139.1
L_{mean}	168.9	152.4	145.2

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

A.3. Impact Pile-Driving Sound Levels rms SPL North

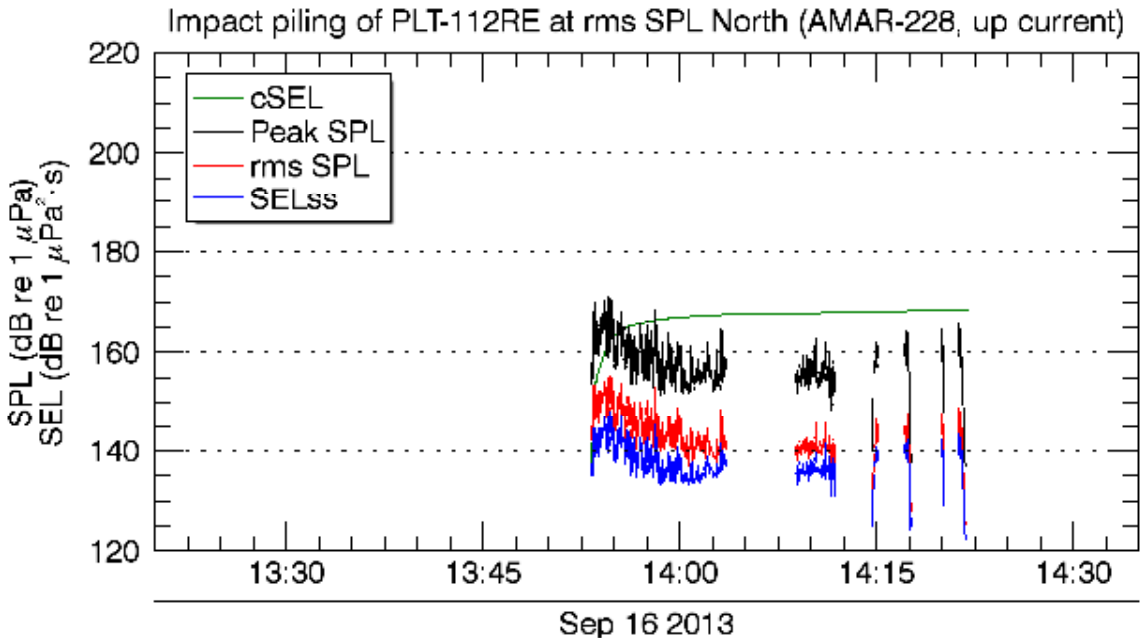


Figure 13. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112RE measured 581 ft from the pile at location rms SPL North using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

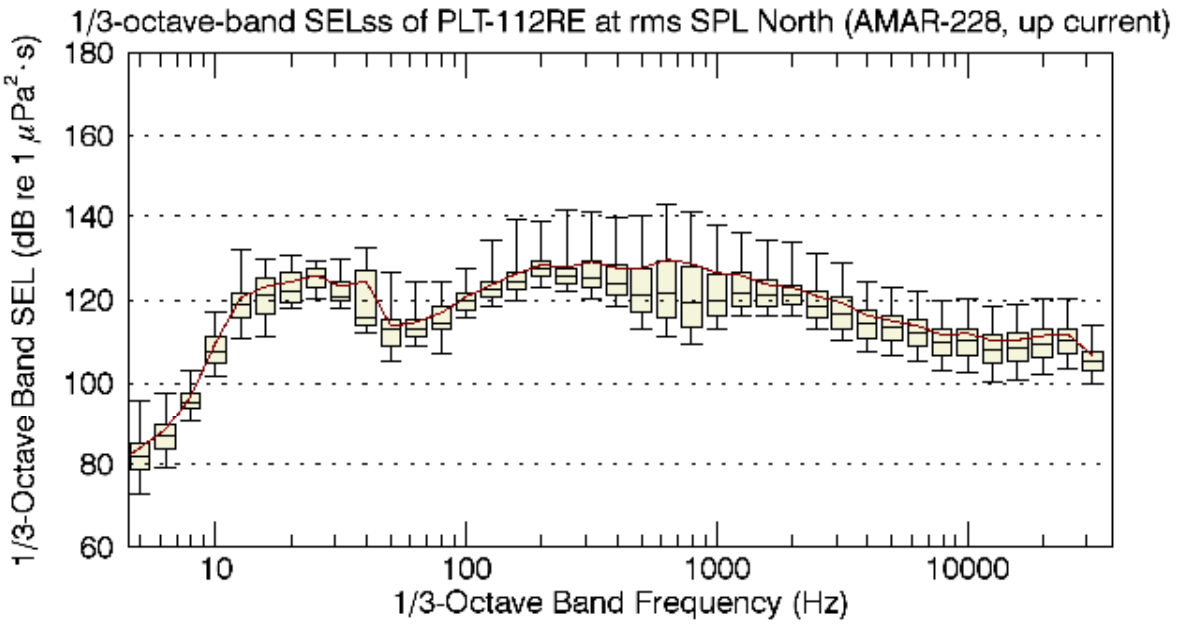


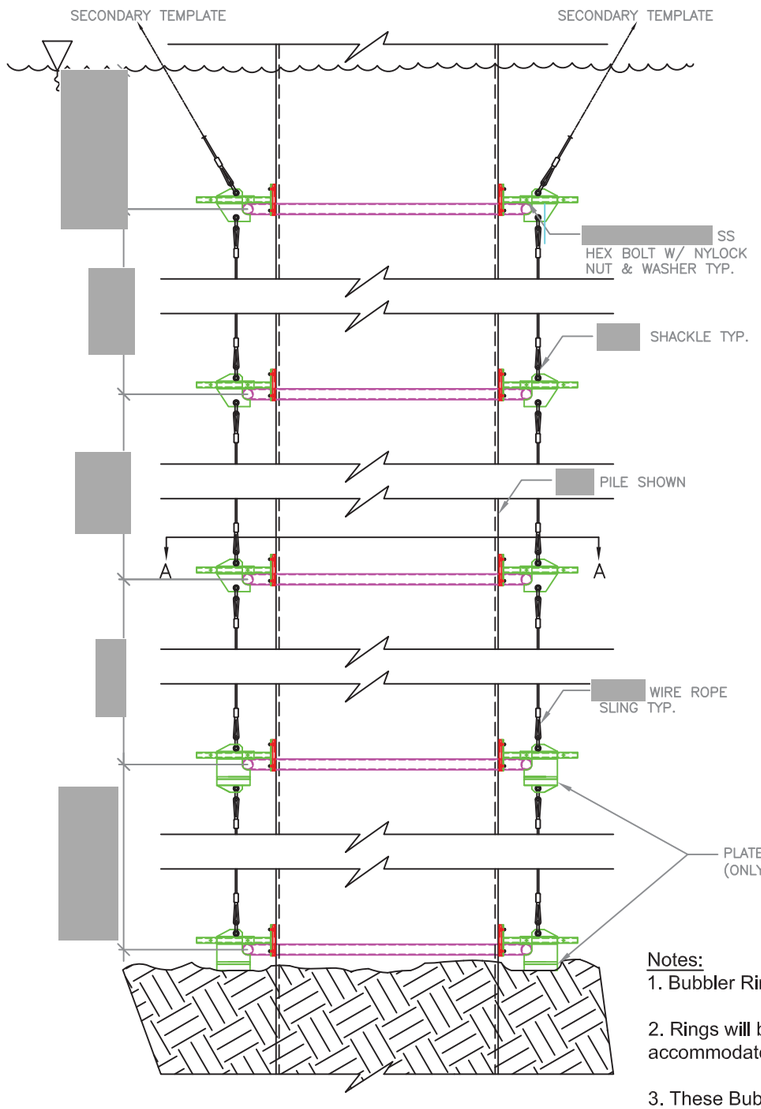
Figure 14. Distribution of 1/3-octave-band-band SELss for the pile driving of Test Pile PLT-112RE measured 581 ft from the pile at location rms SPL North using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 14. Sound levels for the pile driving of Test Pile PLT-112RE measured 581 ft from pile at location rms SPL North using AMAR-228.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa^2·s)
L_{max}	171.0	155.3	148.1
L_5	166.3	151.7	144.2
L_{25}	161.2	146.7	139.9
L_{50}	157.2	142.8	137.0
L_{75}	155.0	140.8	135.4
L_{95}	152.6	139.1	133.9
L_{mean}	160.7	146.1	139.3

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *n*th percentile level (L_n) is the SPL or SEL exceeded by *n*% of the data. L_{max} is the maximum recorded sound level. L_{mean} is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (L_{50}).

Attachment 2 – Design Plans for the Multi-Tier Bubble Curtain (Drawings 1UBCR through 10UBCR)

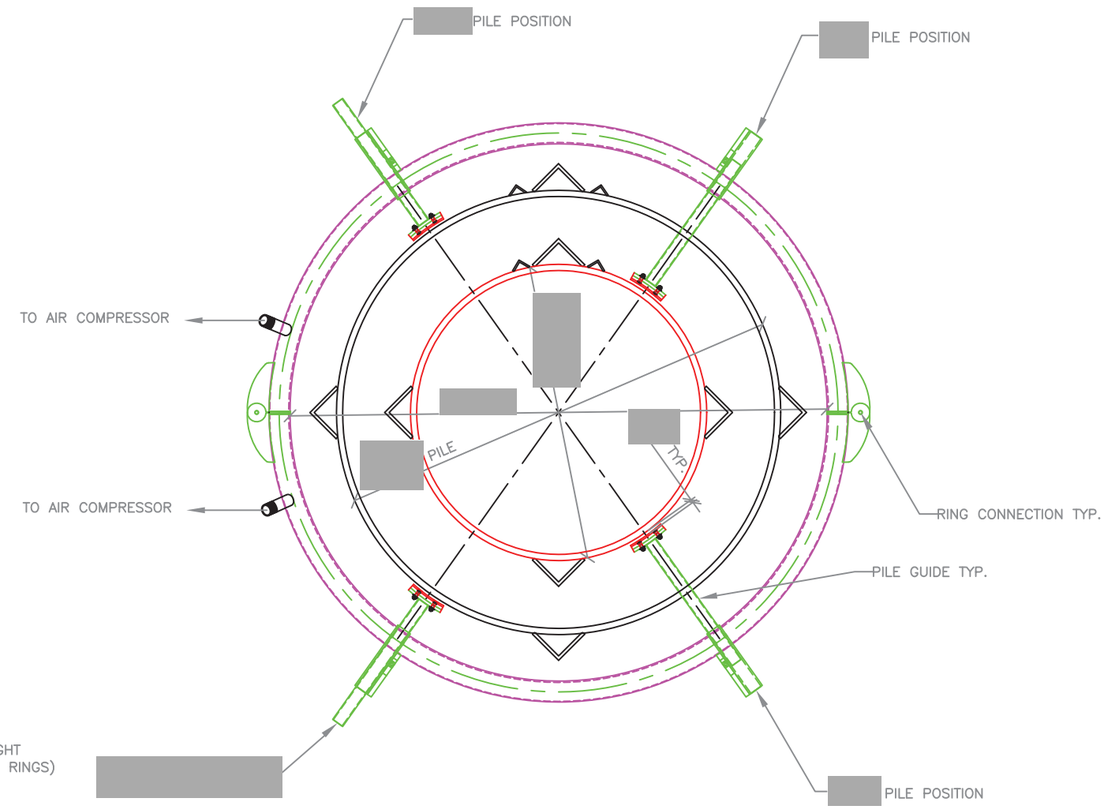


ELEVATION - BUBBLER RINGS PILE
SCALE: NTS

Notes:
1. Bubbler Rings will be spaced at centers maximum

2. Rings will be removed and added as needed to accommodate varying depths

3. These Bubbler Rings can be used on diameter piles



A - PLAN - BUBBLER RINGS
SCALE: NTS

DRAFTED BY: MARTIR_ORTEZ
CHECKED BY: –
DESIGNED BY: –
CHECKED BY: –
DESIGN SUPERVISOR: –

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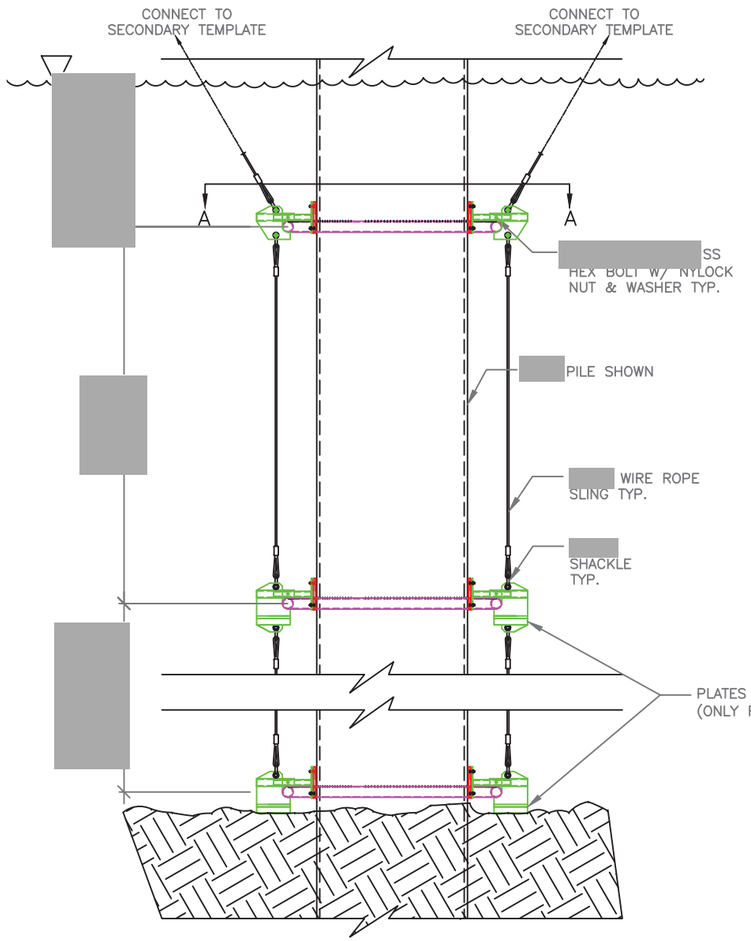
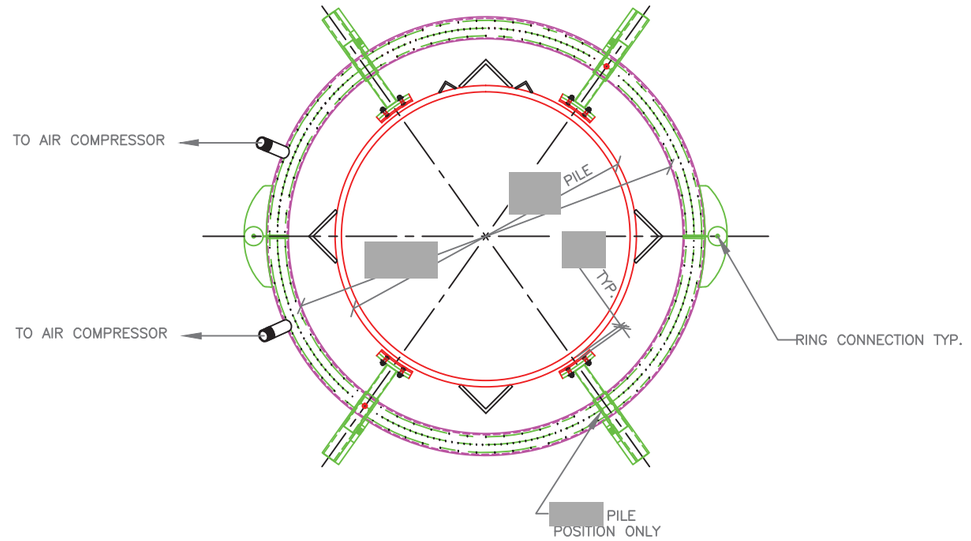


ELEVATION - BUBBLER RINGS PILES
SCALE: NTS



PLAN - BUBBLER RINGS
SCALE: NTS

Notes:
1. Bubbler Rings will be spaced at centers maximum

2. Rings will be removed and added as needed to accommodate varying depths

3. These Bubbler Rings can be used on diameter piles only

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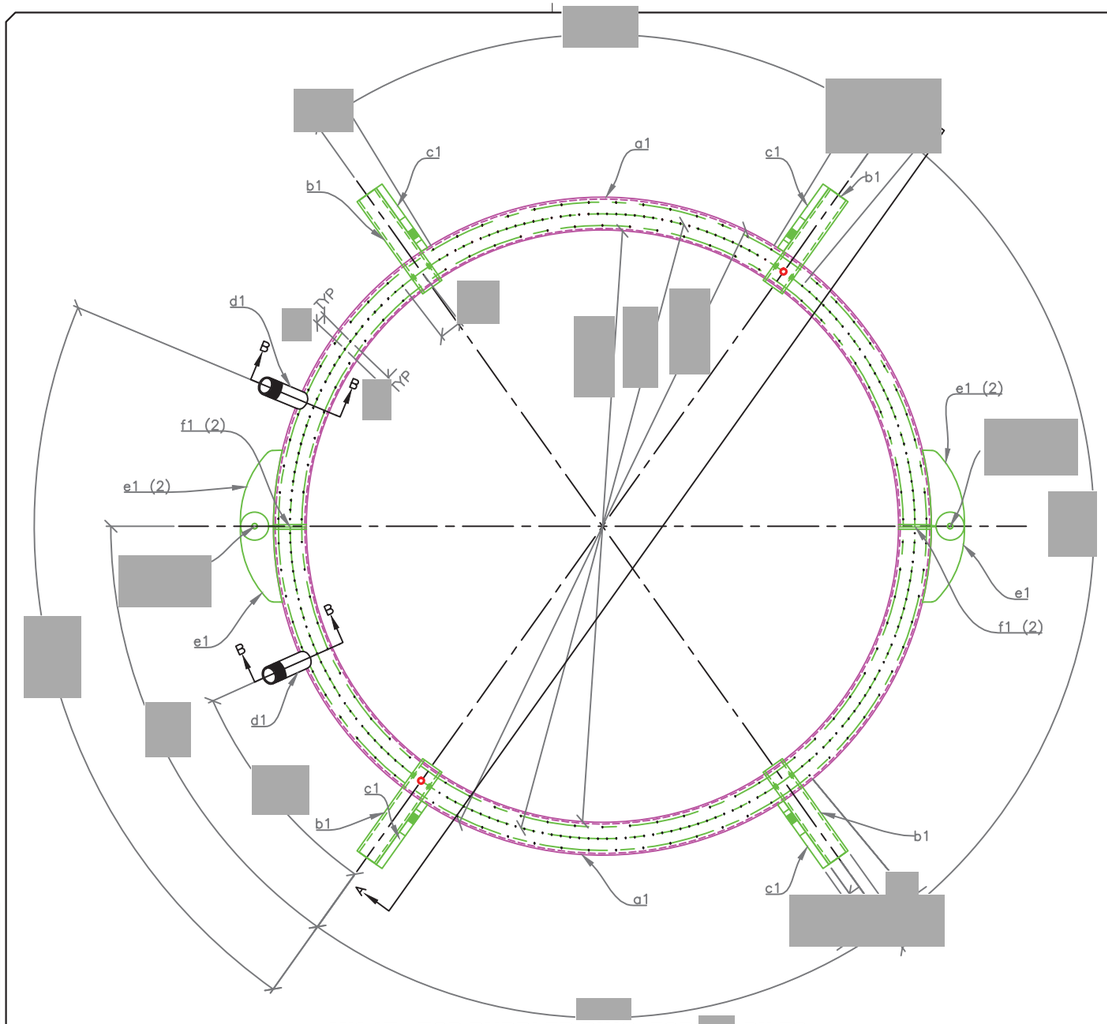

MK 1T - TOP BUBBLER RING FOR [redacted] PILES
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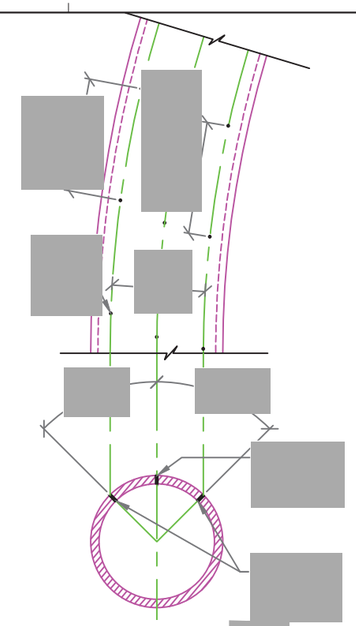
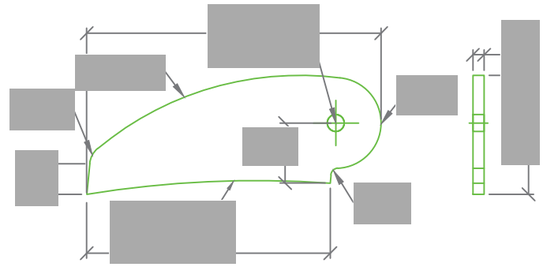


TYPICAL SECTION - [redacted] HOLE LAYOUT
SCALE: NTS

[redacted]



e1-PLATE [redacted] T6061 ALUMINUM
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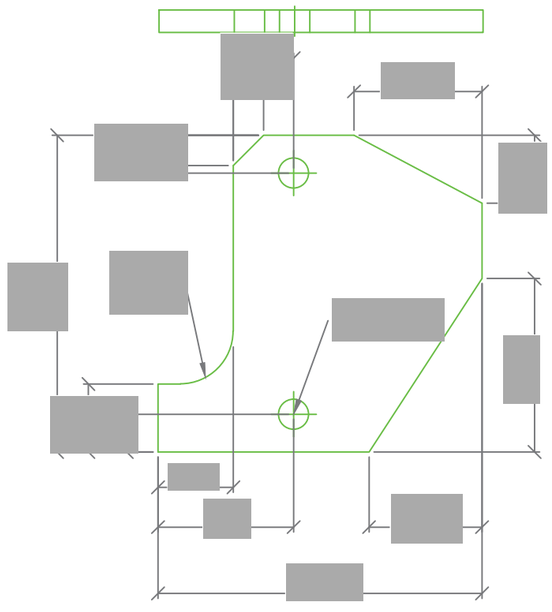
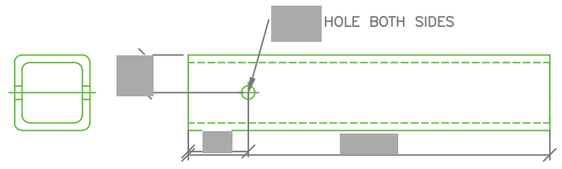


c1-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS



b1-TS [redacted] T6061 ALUMINUM
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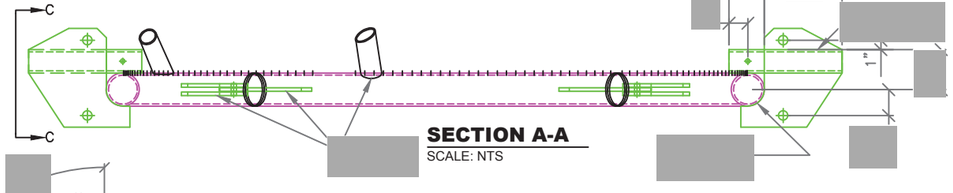
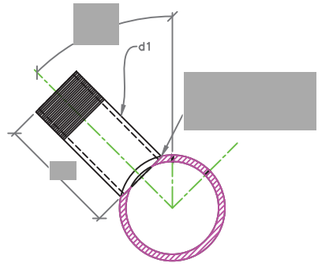
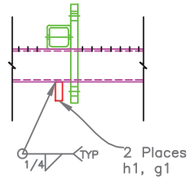


SECTION A-A
SCALE: NTS



SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS



SECTION C-C
SCALE: NTS

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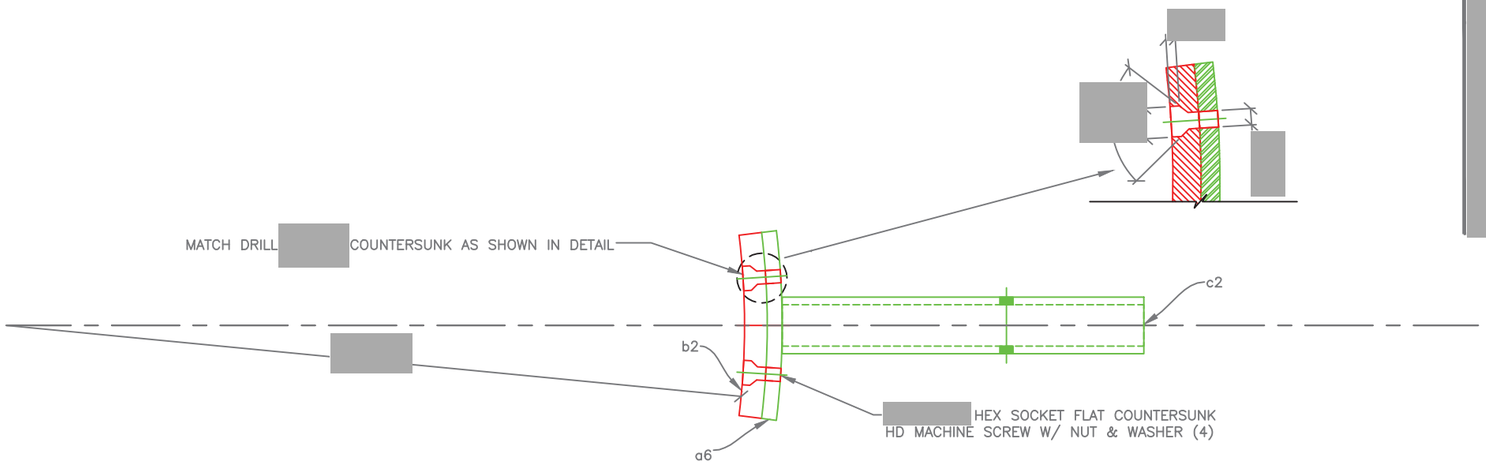
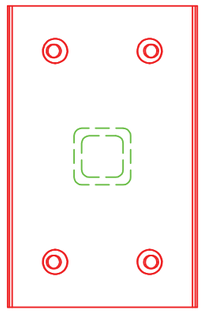
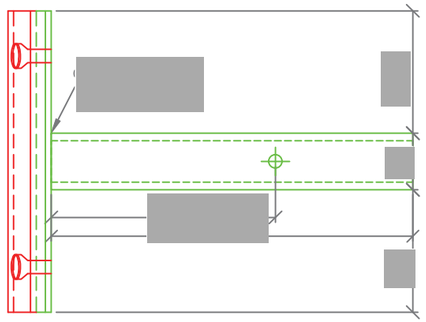
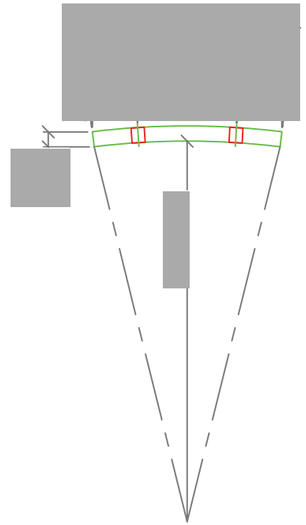
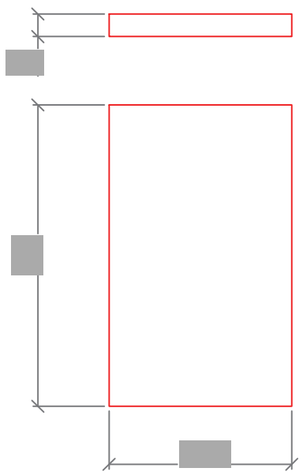




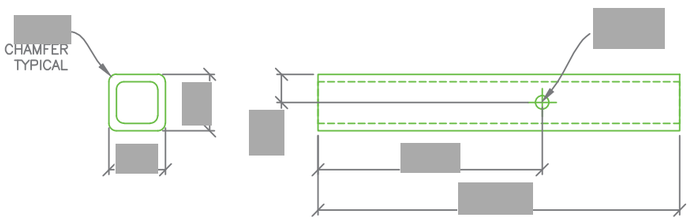




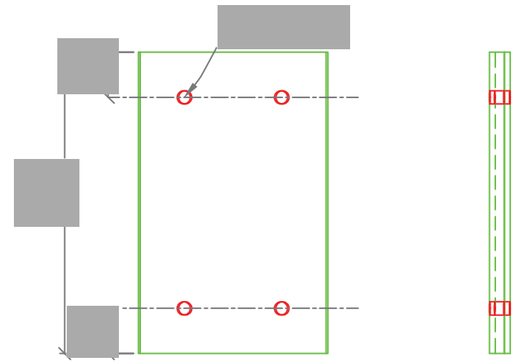
MK 3A - UHMW GUIDES FOR PILES
SCALE: NTS



b2 - UHMW
SCALE: NTS



c2 - SQ T6061 ALUMINUM
SCALE: NTS



a6 - PLATE T6061 ALUMINUM
SCALE: NTS

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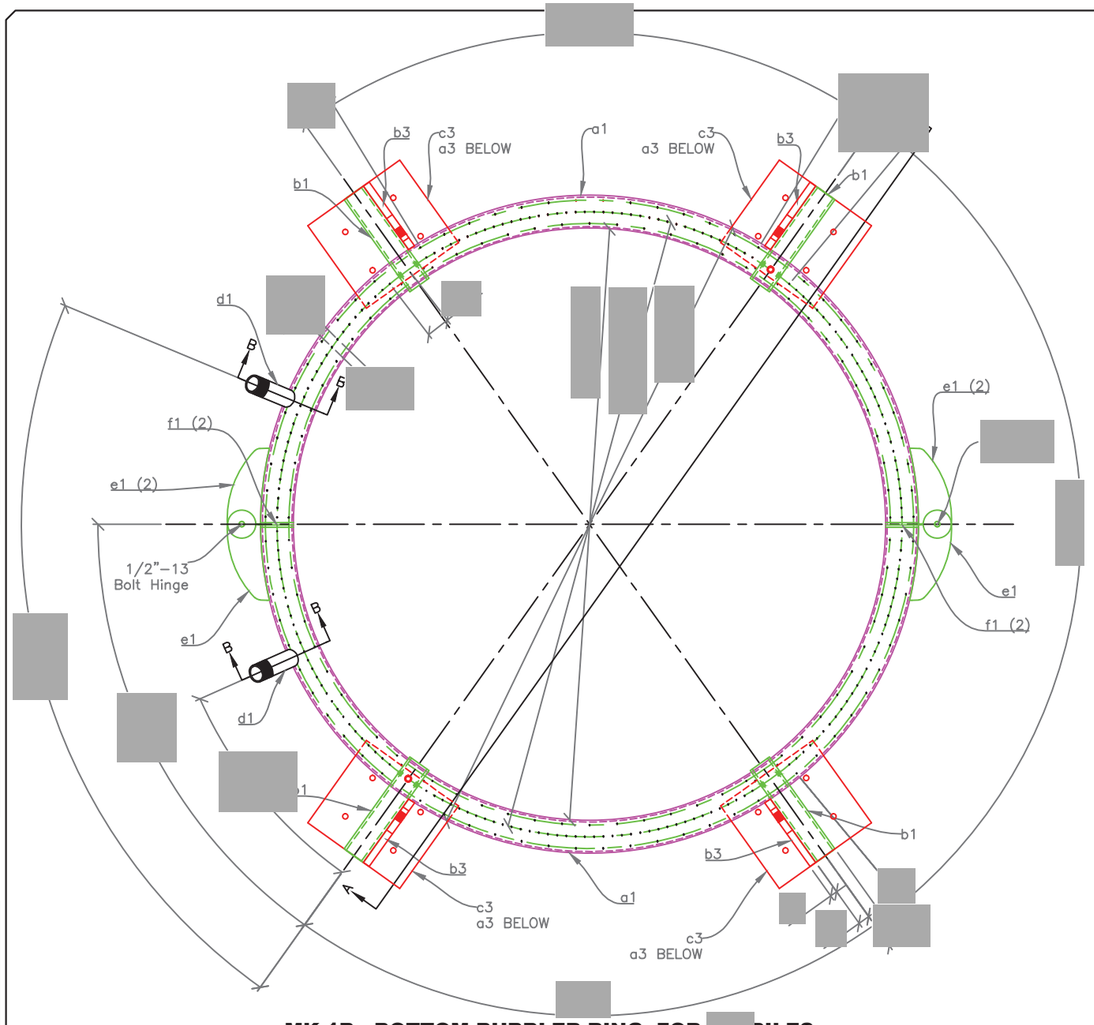

MK 1B - BOTTOM BUBBLER RING FOR [redacted] PILES
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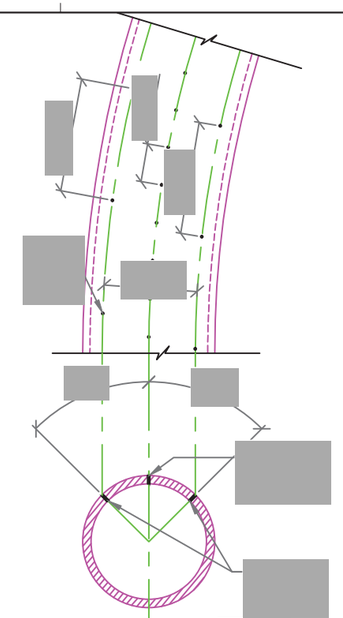
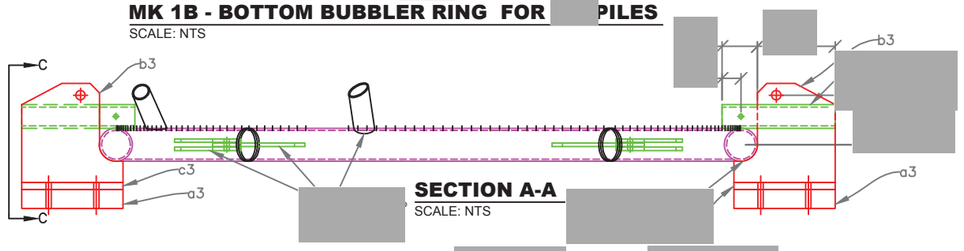
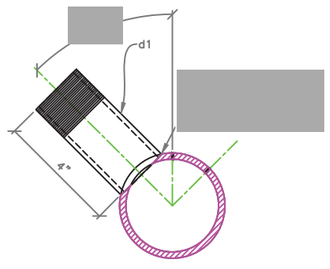


TYPICAL SECTION - [redacted] HOLE LAYOUT
SCALE: NTS

[redacted]



SECTION A-A
SCALE: NTS



SECTION B-B TYPICAL PIPE NIPPLE
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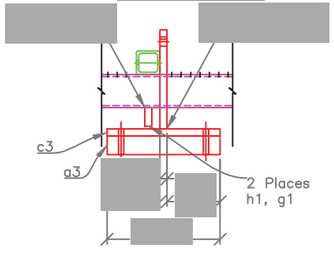
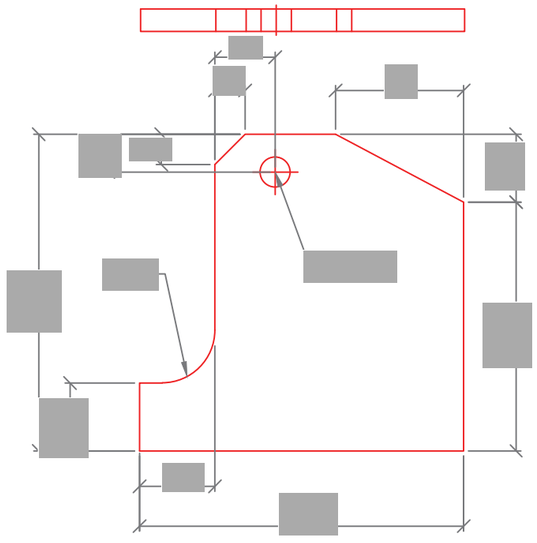
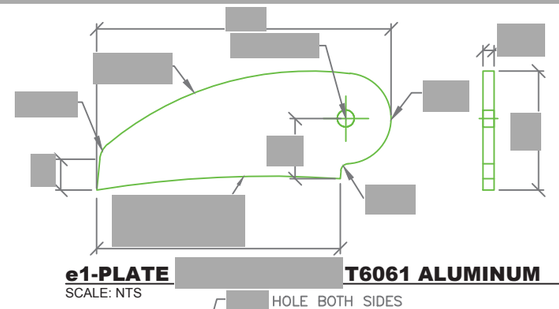


SECTION C-C
SCALE: NTS



b3-PLATE ¾" - T6061 ALUMINUM
SCALE: NTS



e1-PLATE [redacted] T6061 ALUMINUM
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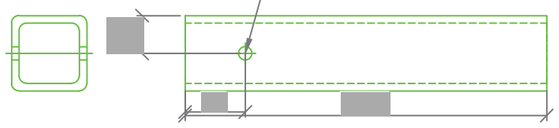

b1-TS [redacted] T6061 ALUMINUM
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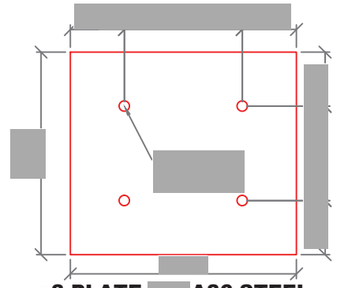
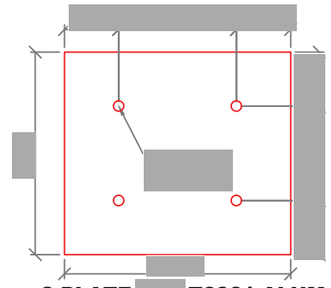


a3-PLATE [redacted] A36 STEEL
SCALE: NTS



c3-PLATE [redacted] T6061 ALUM.
SCALE: NTS

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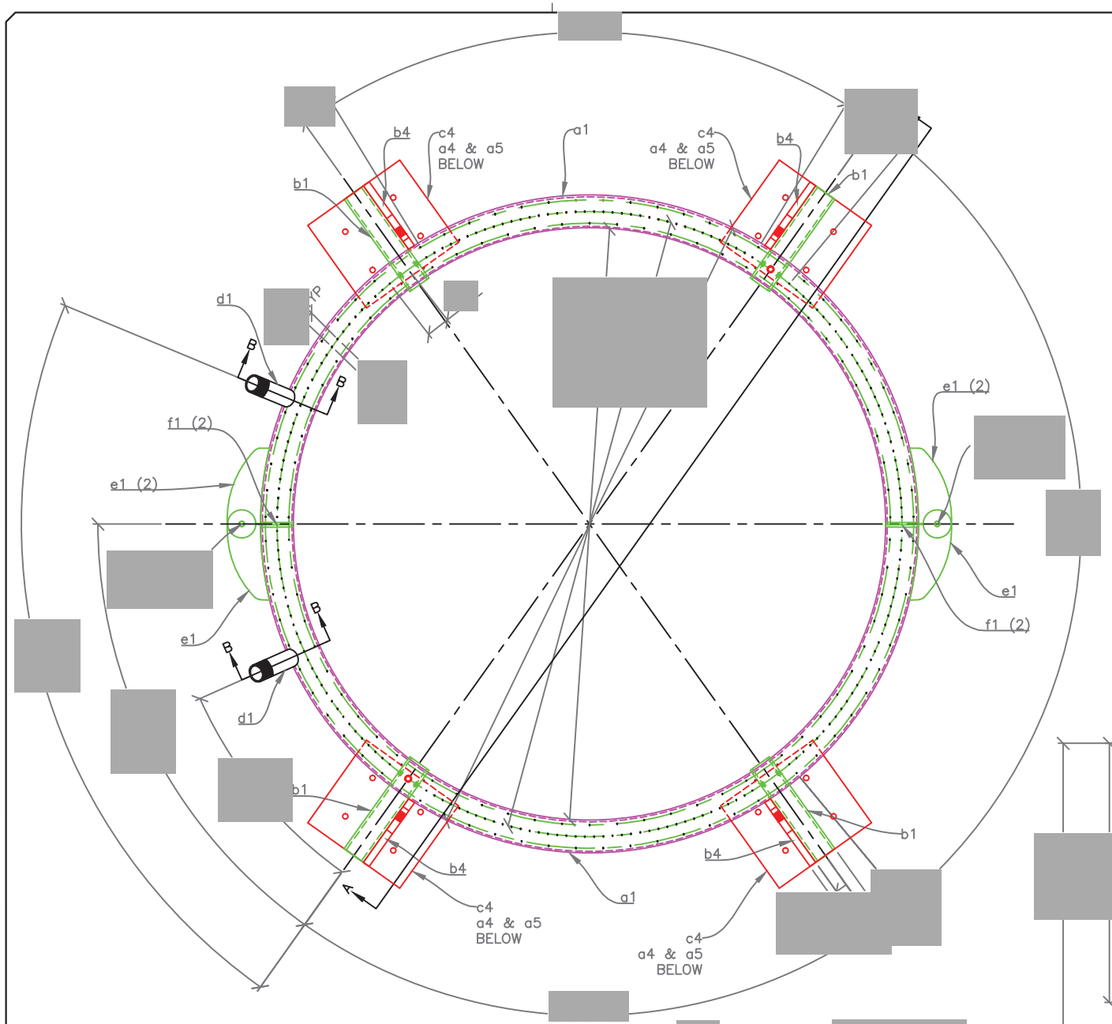
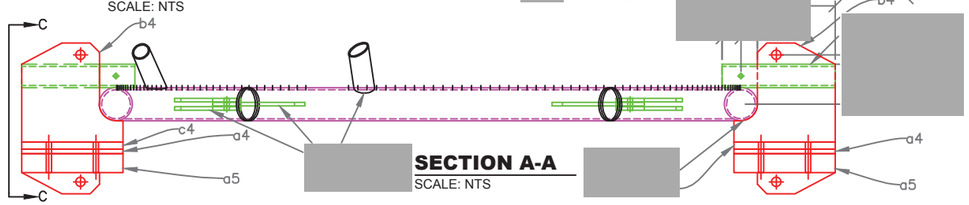
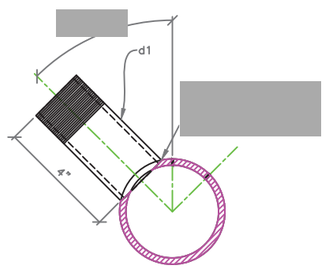


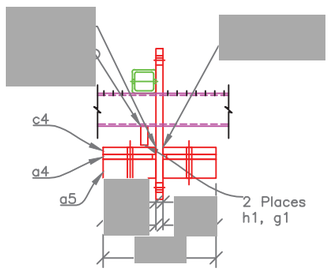
MK 1M - MIDDLE BUBBLER RING FOR PILES
SCALE: NTS



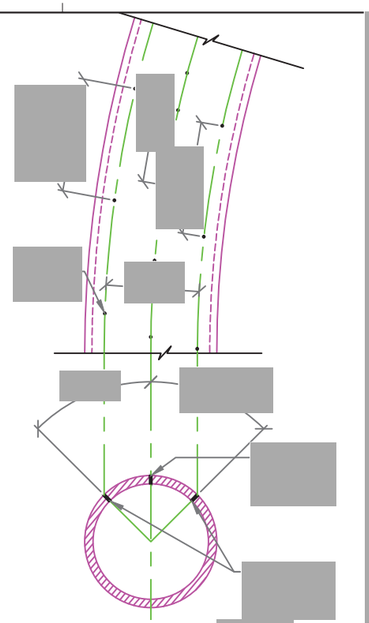
SECTION A-A
SCALE: NTS



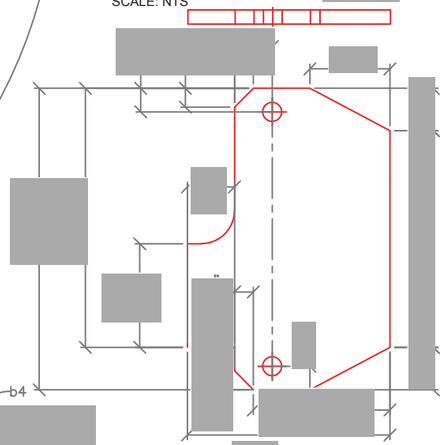
SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS



SECTION C-C
SCALE: NTS



TYPICAL SECTION HOLE LAYOUT
SCALE: NTS



b4-PLATE T6061 ALUMINUM
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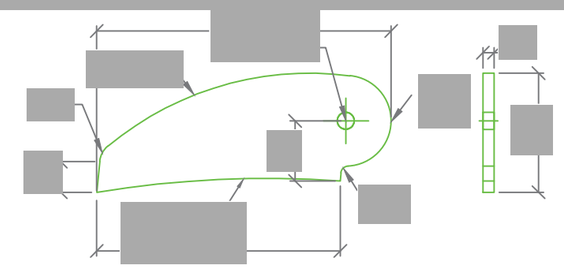

e1-PLATE T6061 ALUMINUM
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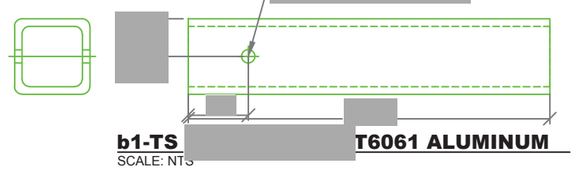

b1-TS T6061 ALUMINUM
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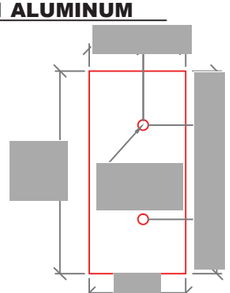
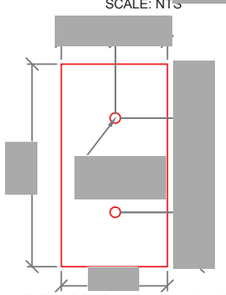
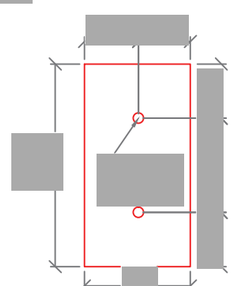


a4-PLATE A36 STEEL
SCALE: NTS



a5-PLATE 2" - A36 STEEL
SCALE: NTS



c4-PLATE T6061 ALUM.
SCALE: NTS

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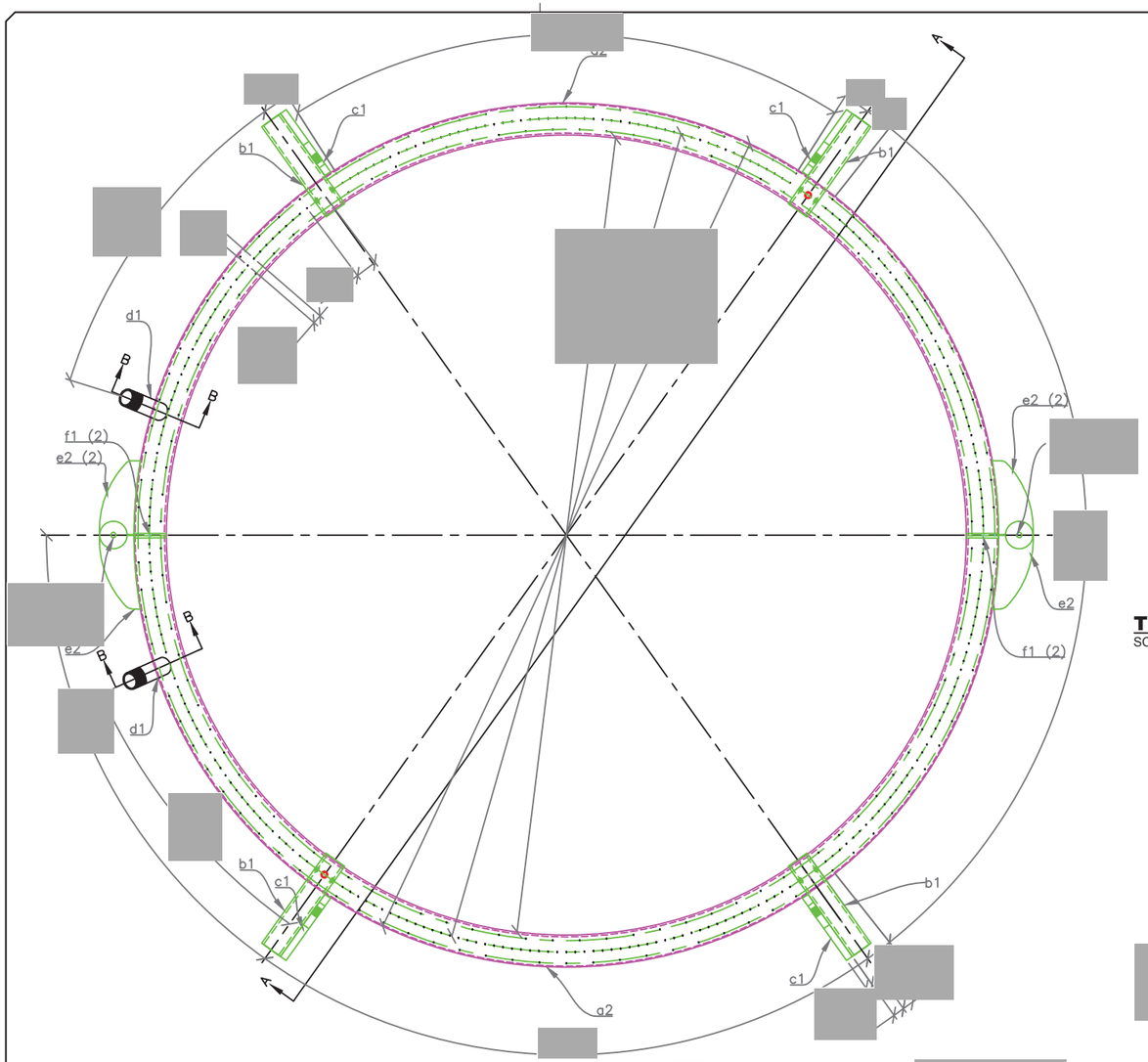
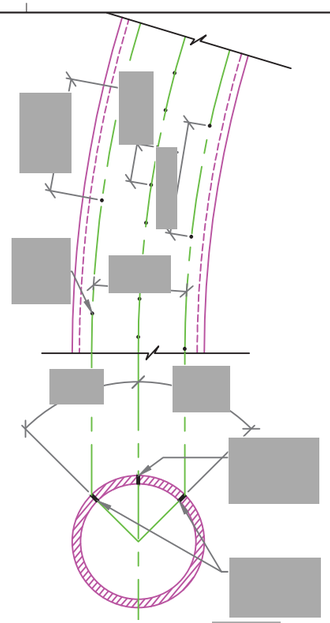
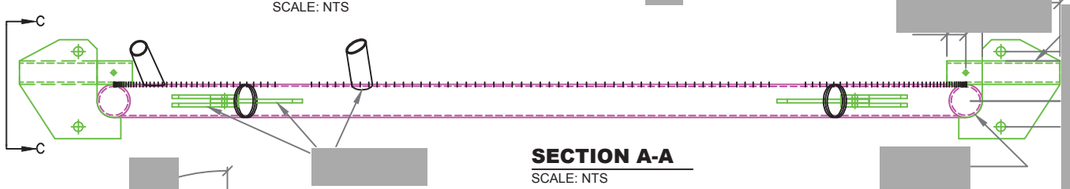


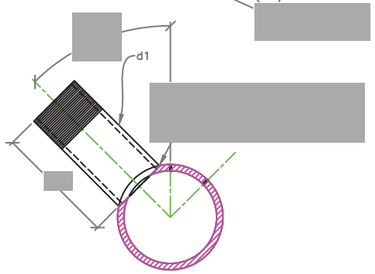
MK 2T - TOP BUBBLER RING FOR PILES
SCALE: NTS



TYPICAL SECTION - HOLE LAYOUT
SCALE: NTS



SECTION A-A
SCALE: NTS



SECTION B-B TYPICAL PIPE NIPPLE
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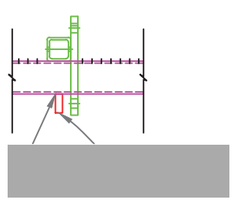
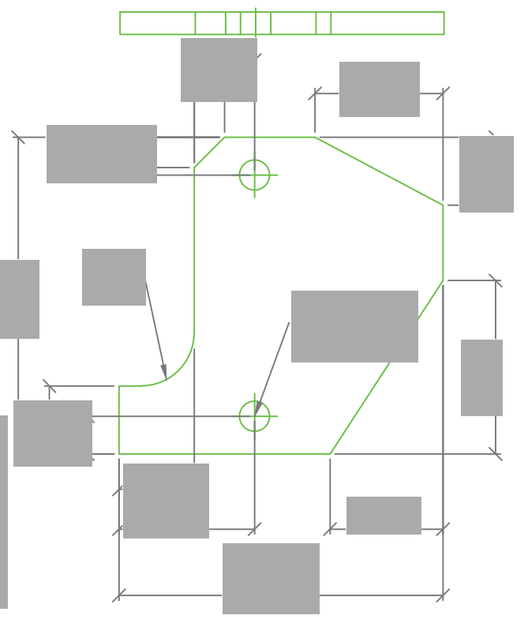
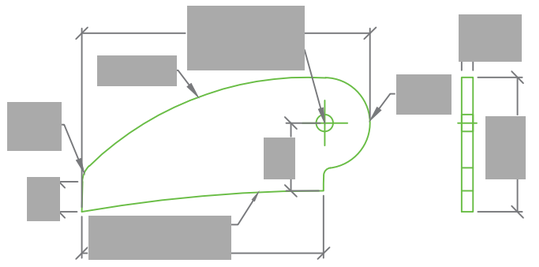


SECTION C-C
SCALE: NTS



c1-PLATE T6061 ALUMINUM
SCALE: NTS



e2-PLATE T6061 ALUMINUM
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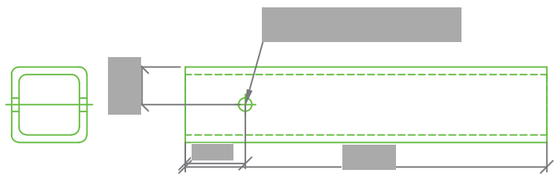


b1-TS T6061 ALUMINUM
SCALE: NTS

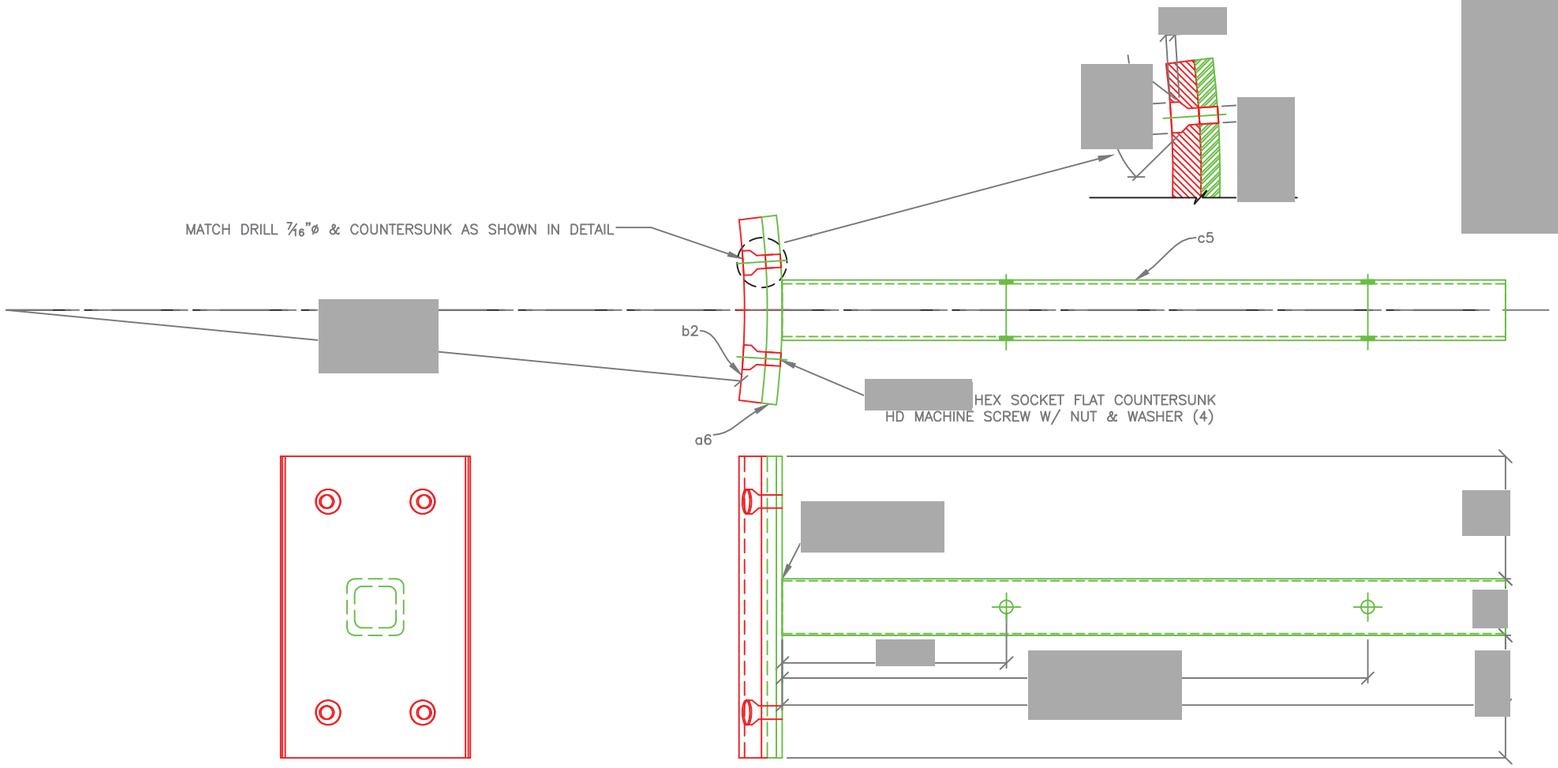
REVISIONS			
DATE	DESCRIPTION	BY	SYM.

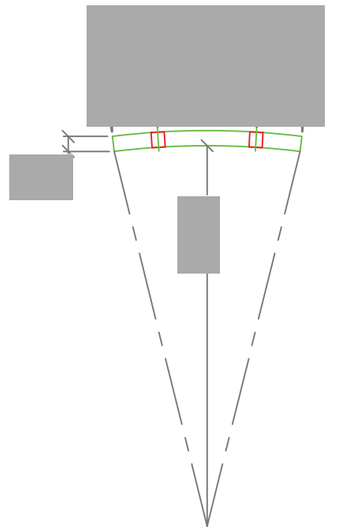
NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

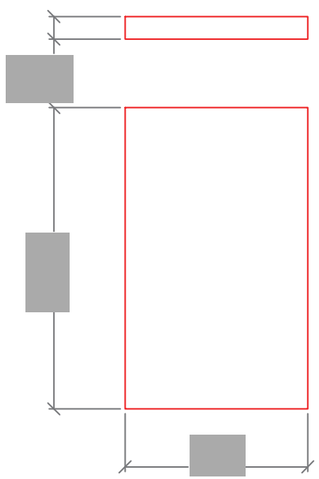
TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
CONTRACT NUMBER: –
DATE: 5/19/13
DRAWING NUMBER: 7UBCR

DESIGN SUPERVISOR: –
DESIGNED BY: –
DRAFTED BY: MARTIR_ORTEZ
CHECKED BY: –
DOCUMENT TRACKING CODE: -





MK 3B - UHMW GUIDES FOR PILES
SCALE: NTS



b2 - UHMW
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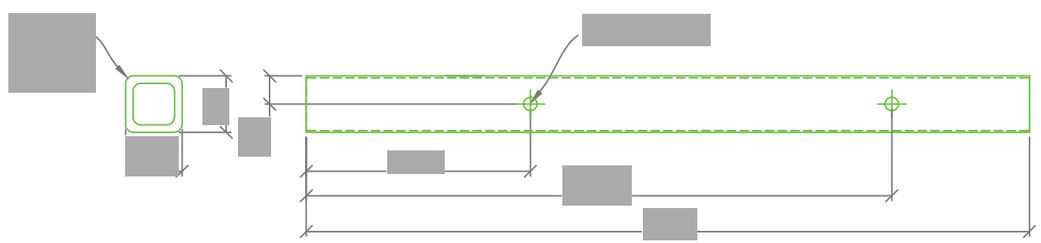

c5 - SQ T6061 ALUMINUM
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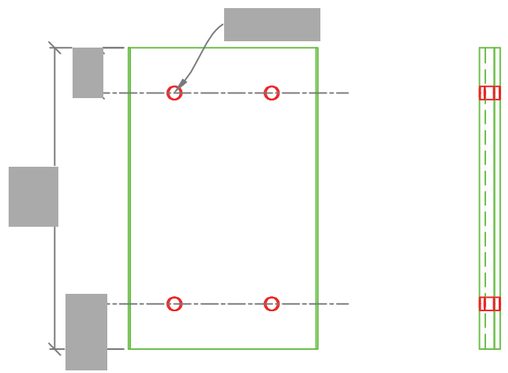

a6 - PLATE T6061 ALUMINUM
SCALE: NTS

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NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
–
LOCATION OF PROJECT: NEW_YORK_STATE
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CONTRACT NUMBER: –
DATE: 5/19/13
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DESIGN SUPERVISOR: –
DESIGNED BY: –
DRAFTED BY: MARTIR_ORTEZ
CHECKED BY: –
DOCUMENT TRACKING CODE: –

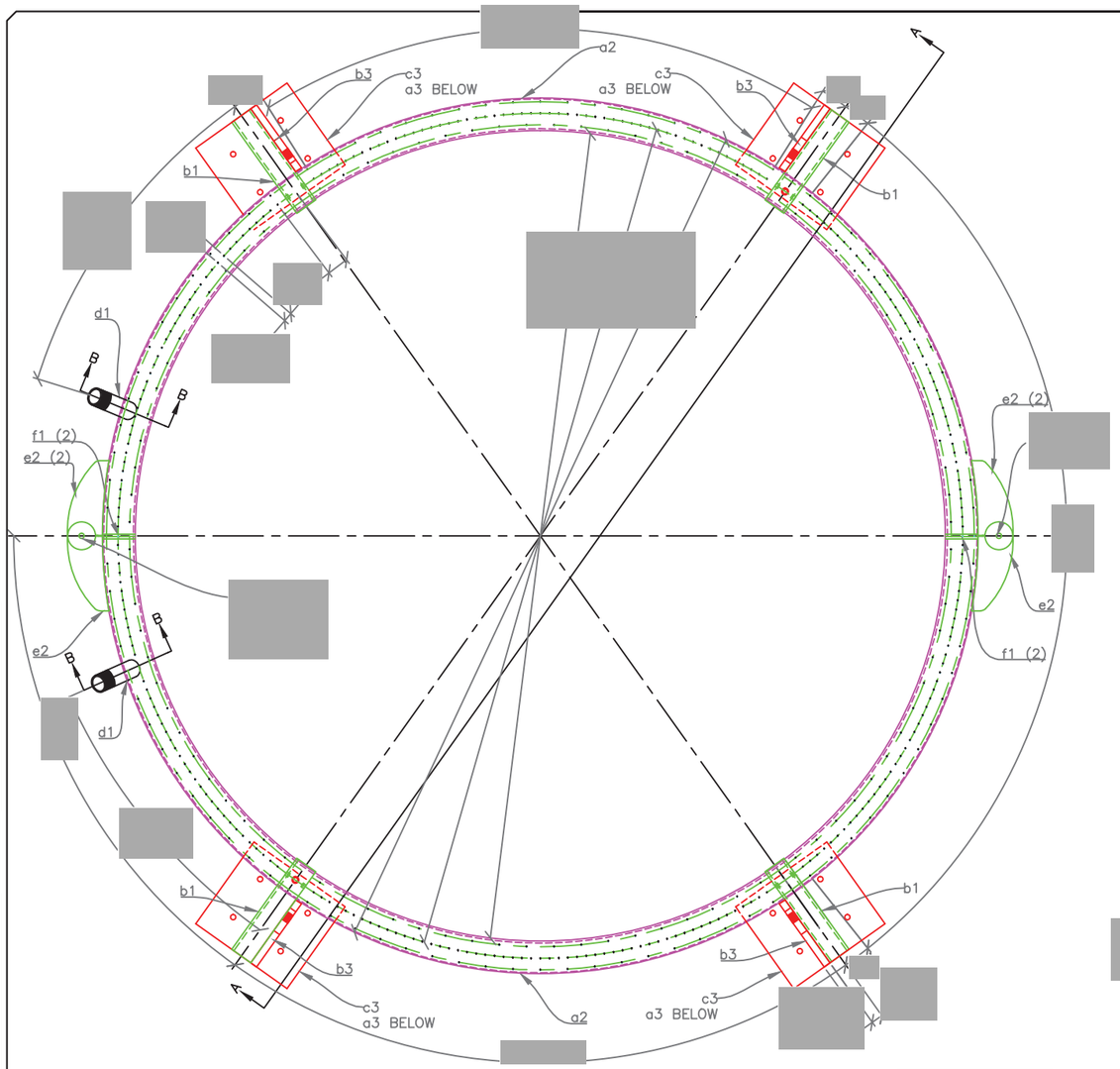
CHECKED BY: -

DRAFTED BY: MARTIR_ORTEZ

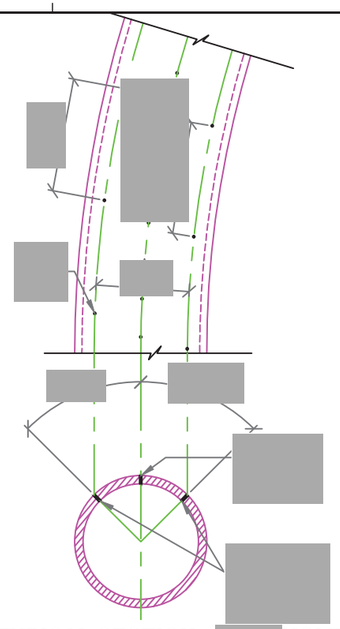
CHECKED BY: -

DESIGNED BY: -

DESIGN SUPERVISOR: -

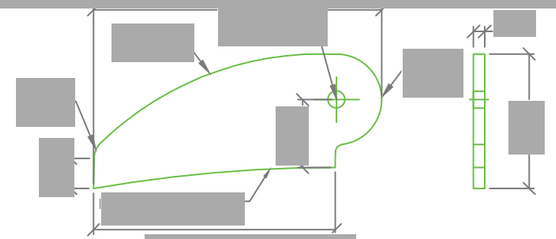


MK 2B - BOTTOM BUBBLER RING FOR [redacted] PILES
SCALE: NTS



TYPICAL SECTION - [redacted] HOLE LAYOUT
SCALE: NTS

[redacted]



e2-PLATE [redacted] T6061 ALUMINUM
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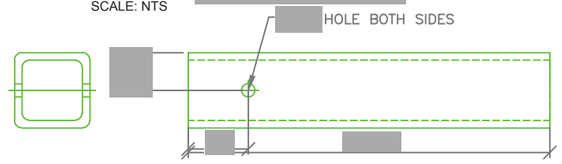
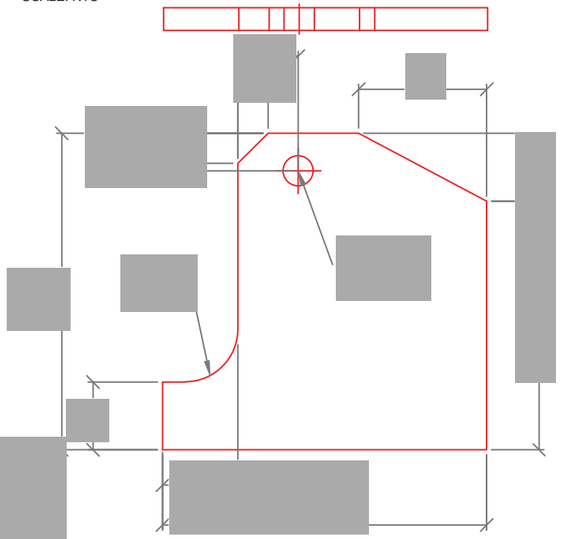


b1-TS [redacted] T6061 ALUMINUM
SCALE: NTS



b3-PLATE [redacted] T6061 ALUMINUM
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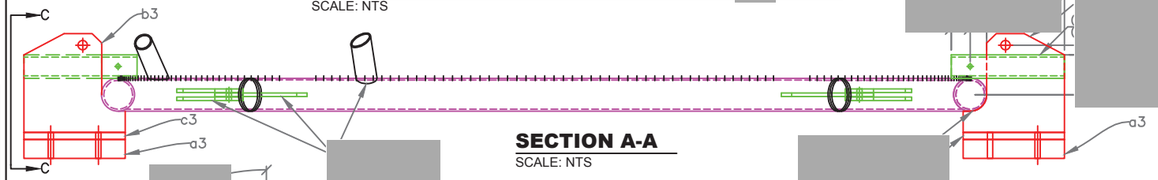
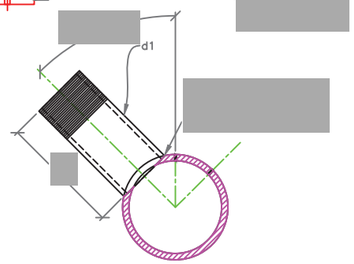
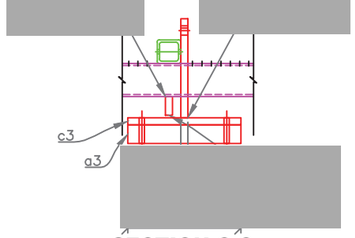


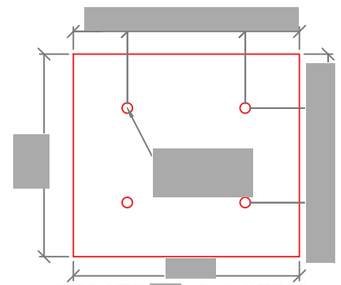
SECTION A-A
SCALE: NTS



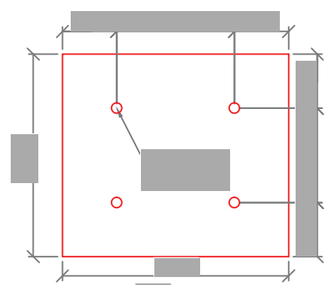
SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS



SECTION C-C
SCALE: NTS



a3-PLATE [redacted] - A36 STEEL
SCALE: NTS



c3-PLATE [redacted] - T6061 ALUM.
SCALE: NTS

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
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LOCATION OF PROJECT: NEW_YORK_STATE
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DESIGNED BY:
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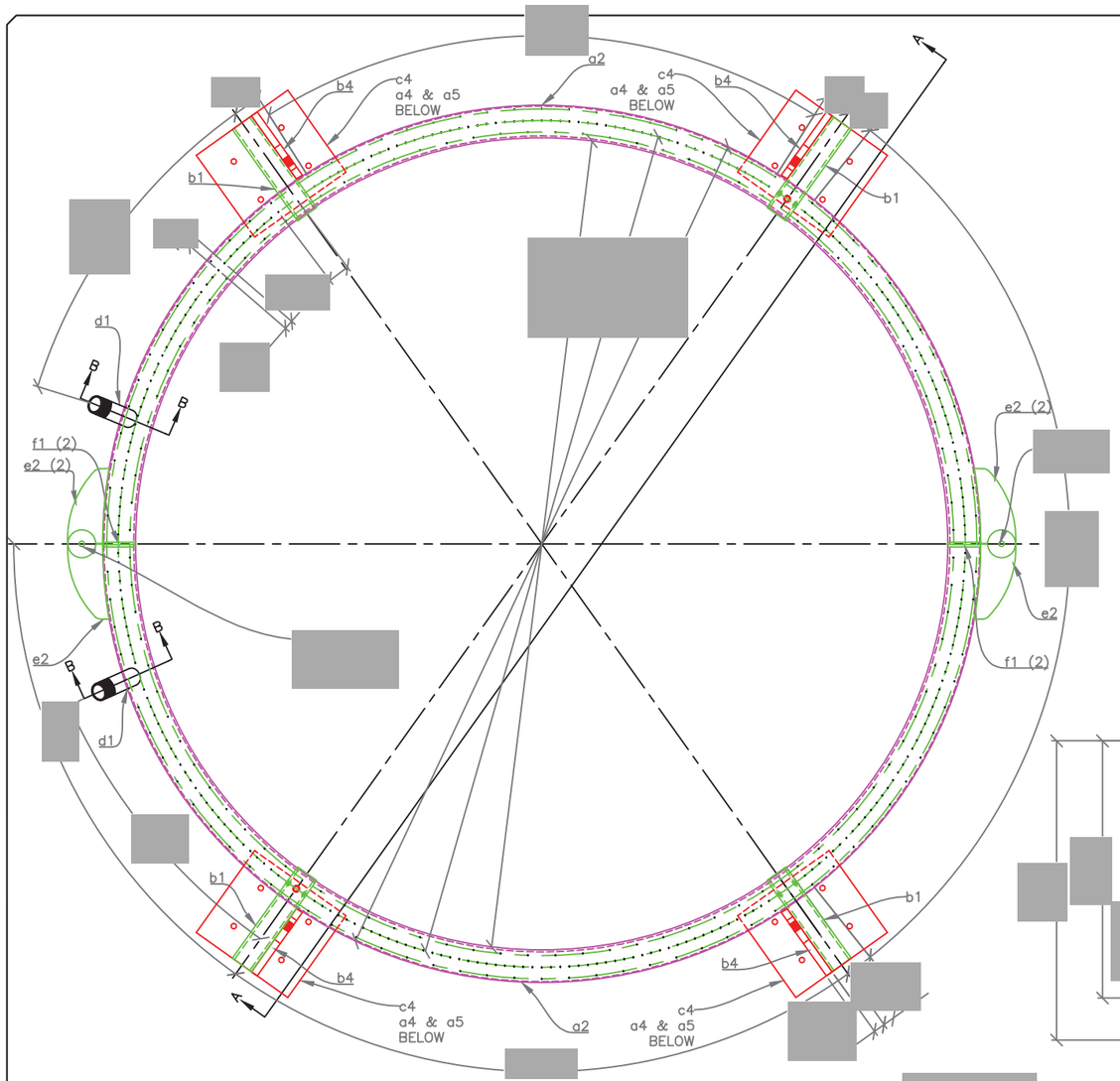
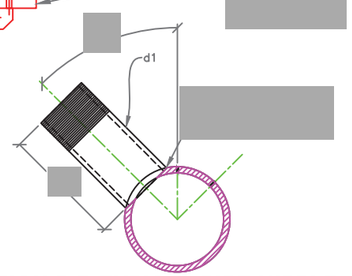


MK 2M - MIDDLE BUBBLER RING FOR PILES
SCALE: NTS

SECTION A-A
SCALE: NTS



SECTION B-B TYPICAL PIPE NIPPLE
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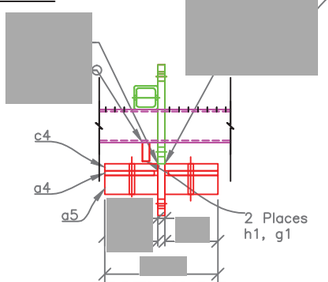
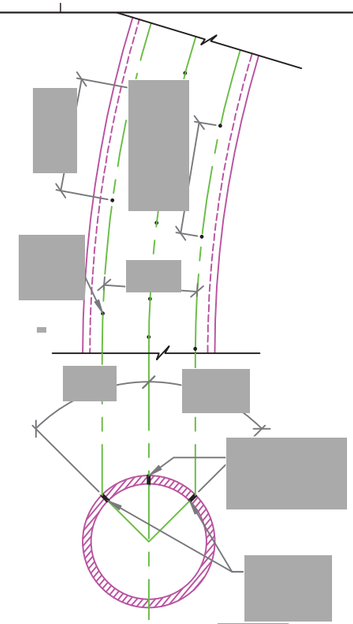
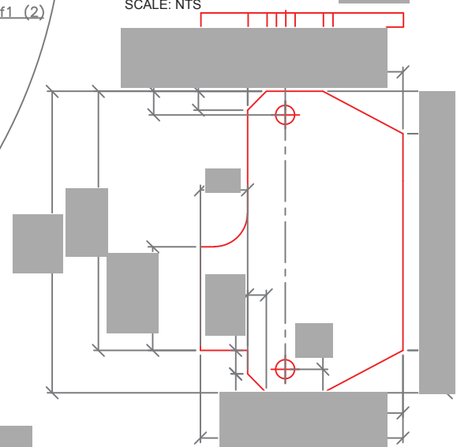


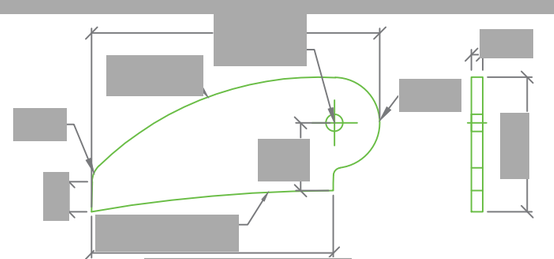
SECTION C-C
SCALE: NTS



TYPICAL SECTION - HOLE LAYOUT
SCALE: NTS



b4-PLATE T6061 ALUMINUM
SCALE: NTS



e2-PLATE T6061 ALUMINUM
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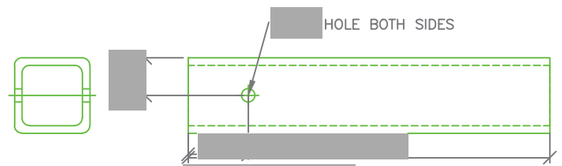

b1-TS T6061 ALUMINUM
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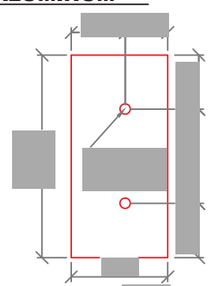
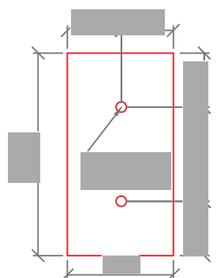
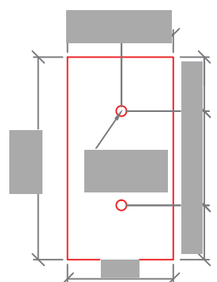


a4-PLATE A36 STEEL
SCALE: NTS



a5-PLATE - A36 STEEL
SCALE: NTS



c4-PLATE T6061 ALUM.
SCALE: NTS

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
CONTRACT NUMBER: –
DATE: 5/19/13
DRAWING NUMBER: 10UBCR

DOCUMENT TRACKING CODE: -

Attachment 3 – Air Compressor Specifications

Atlas Copco Rental

PTS 916

100% Oil-free Air Compressor - Diesel driven - TIER III compliant

Atlas Copco Rental is the leader in 100% oil-free air compressor rentals and maintains a strong commitment to customer service and availability, with locations across North America. A highly specialized service team is readily accessible 24/7 when you work with the Atlas Copco Rental team.

Sustainable Productivity

Atlas Copco

PTS 916 100% Oil-free Air Compressor

General	
Dimensions LxWxH	17'8" x 7'3" x 7'9"
Shipping weight (wet)	18,600 lbs / 8,437 kg
Fuel tank capacity	237 gal / 900 l
Sound pressure level LPA	74 dB (A)
Sound power level LWA	102 dB (A)

Engine	
Engine make	Caterpillar
Type	C18 Acert
Output	575 HP / 429 kW
Fuel consumed (Gal/Hr)	22

Compressor	
Number of stages	2
Maximum capacity FAD l/s	762
Maximum capacity FAD m³/min	45.7
Maximum capacity FAD cfm	1,600

Performance

Working Pressure		Free Air Delivery		
bar(e)	*psig*	*m³/min*	*m³/H*	*cfm*
6.9	10-150	45.7	2,742	1,300-1,600
9.3	135	43.1	2,586	1,522
10.3	150	37.4	2,244	1,321

Other Features

- Integrated aftercooler (15°F + A)
- Spillage free frame
- Weatherproof canopy
- Spark arrestor
- Overspeed shut down system
- Cold weather package
- Auxillary tank hook-ups w/ switching valves
- Operator safety devices:
  - Emergency stop buttons
  - Warning light
  - Alarm horn

Never use compressed air as breathing air without prior purifcation in accordance with local legislation and standards.

CLASS 0 ISO 8573-1

The TÜV found no traces of oil in the output air stream. Atlas Copco has thereby become the first compressor manufacturer to receive certification for a new industry standard of air purity: **ISO 8573-1 CLASS 0.** More information can be found on: **www.classzero.com**

All Routine Service Included

We provide routine maintenance at no charge. No hidden costs!

Additional Rental Product Solutions

- Boosters
- Dryers
- Fuel Tanks (double wall)
- Hoses
- Manifolds
- Nitrogen Generation Equipment
- Particulate Discharge Scrubbers
- Trailers

Triple certification, Triple benefit

LLOYD'S REGISTER QUALITY ASSURANCE ISO9001 · ISO14001 · OHSAS 18001

24/7 Rental Service all across USA and Canada
1-800-736-8267
www.AtlasCopcoRental.com