Description of Underwater Noise Attenuation System
Design Unit 4
for the
New NY Bridge Project

Revision 2
April 17, 2014

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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 upon 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 with 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 report compared the NASs that were considered for possible adoption based upon the 2012 Pile Installation Demonstration Program (PIDP). The report also 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 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 that were established by the BO Term and Condition 9 and by 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.

That report 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 *PLT-NAS Description* 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 underwater sound attenuation system monitoring, as well as the monitoring locations for production pile driving. The purpose of the present Report is to provide the results of the underwater noise monitoring of the installation of test piles for the Design Unit 4 (see Attachment 1) and based on those results, provide the design plans and anticipated operational specifications for the noise attenuation system for Design Unit 4 in accordance with the following NYSDEC Permit Conditions 8 and 9:

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 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 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 Test Piles

The Pile Load Test Program uses test piles in each of the 10 design units plus the Main Span (11 total design units), with the primary purpose to confirm pile load capacities. Design Unit 4 consists piles in Piers Test piles were installed with an IHC S-280 impact hammer. A summary of the impact pile driving for test piles at Design Unit 4 is provided in Table 1.

Table 1. Summary of Impact Pile Driving for Test Piles at Design Unit 4

Test Pile	Pile Diameter	Impact Hammering Date
PLT-106		8/26/2013
PLT-106P		8/27/2013
PLT-107P		10/8/2013
PLT-107		10/8/2013

3.0 Unconfined Multi-tier Air 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 2 for engineering details on the system.

3.1.1 NAS Components

The unconfined multi-tier bubble curtain consists of aluminum bubbler ring(s) suspended from the pile-driving template at four points, spaced a maximum of 10 feet vertically, and connected to the template using ½”-diameter wire rope. See Attachment 2 for bubbler ring dimensions and hole diameter, spacing, and orientation.

The aluminum ring was connected to a dedicated compressor (Figure 1). This compressor was connected to a reservoir tank to allow a continuous supply of air throughout pile driving (Figure 1). During the installation of test piles, a flow meter and air pressure gauge were used to measure air flow and pressure (Figure 2). The air compressor is capable of supplying an air pressure of up to 100 pounds per square inch (psi) at an air flow of 1600 cubic feet per meter (cfm) to each bubbler ring (Attachment 3). The reservoir tank allows the system to supply an air flow of up to 2000 cfm to each bubbler ring, as was demonstrated during testing.

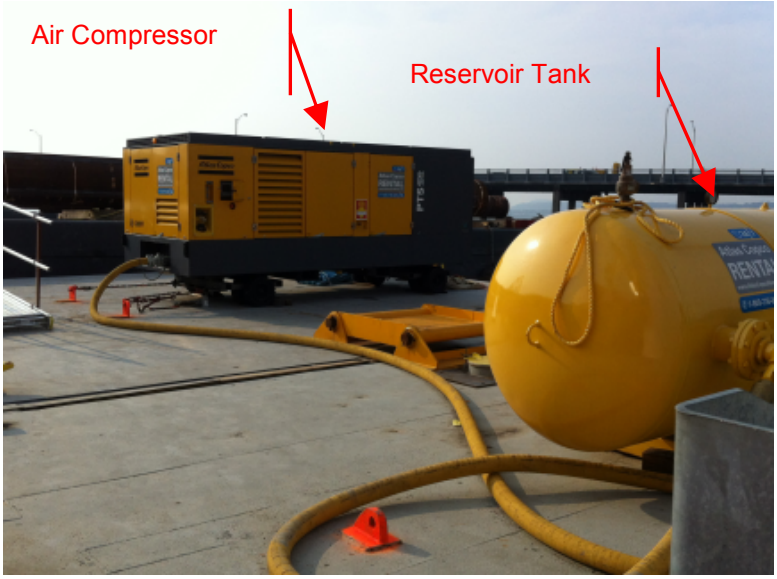

Figure 1. Air Compressor and Reservoir Tank

Figure 2. Flow Meter and Pressure Gauge on Outlets from the Reservoir Tank to the Bubbler Ring

3.1.2 NAS Deployment and Operation

The NAS deployment and operation proceeded as expected. After the piles were initially driven with the vibratory hammer, the bubble curtain ring was deployed with a crane and hung from the secondary template, using wire rope slings and shackles (Figure 3). The air compressor/reservoir tank pumped air into the ring (Figure 4), 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 3. Deployment of the Unconfined Multi-tier Bubble Curtain

Figure 4. 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 noise monitoring are included in the Underwater Noise Monitoring Plan. Details on the underwater noise monitoring during the installation of PLT 106, PLT 106P, PLT 107P, and PLT 107 are provided in the Daily Memoranda for the monitoring of each test pile (Attachment 1).

Figure 5 provides a typical barge and hydrophone arrangement [redacted] As illustrated in Figure 5, a real time Autonomous Multichannel Acoustic Recorder (AMAR-RT) and two 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). The AMAR-RT was continuously monitored through out the pile driving process while data collected from the AMARs was downloaded following pile driving. The noise level thresholds predicted in the NMFS BO (April 2013) are as follows:

- peak SPL (sound pressure level) – located on the barge or survey vessel, approximately 33 feet from the pile, based on the distance that can be safely recorded (the distance to the 206 re 1 μPa peak SPL isopleth for [redacted] piles is 20 feet)
- cSEL (cumulative Sound Exposure Level) – located approximately 132 feet from the pile, based on the distance from the pile to the 187 dB re 1 μPa^2-s cSEL isopleth for [redacted] piles
- rms SPL (root mean square SPL) – located approximately 400 feet from the pile, based on the distance from the pile to the 150 dB re 1μPa rms SPL for [redacted] piles

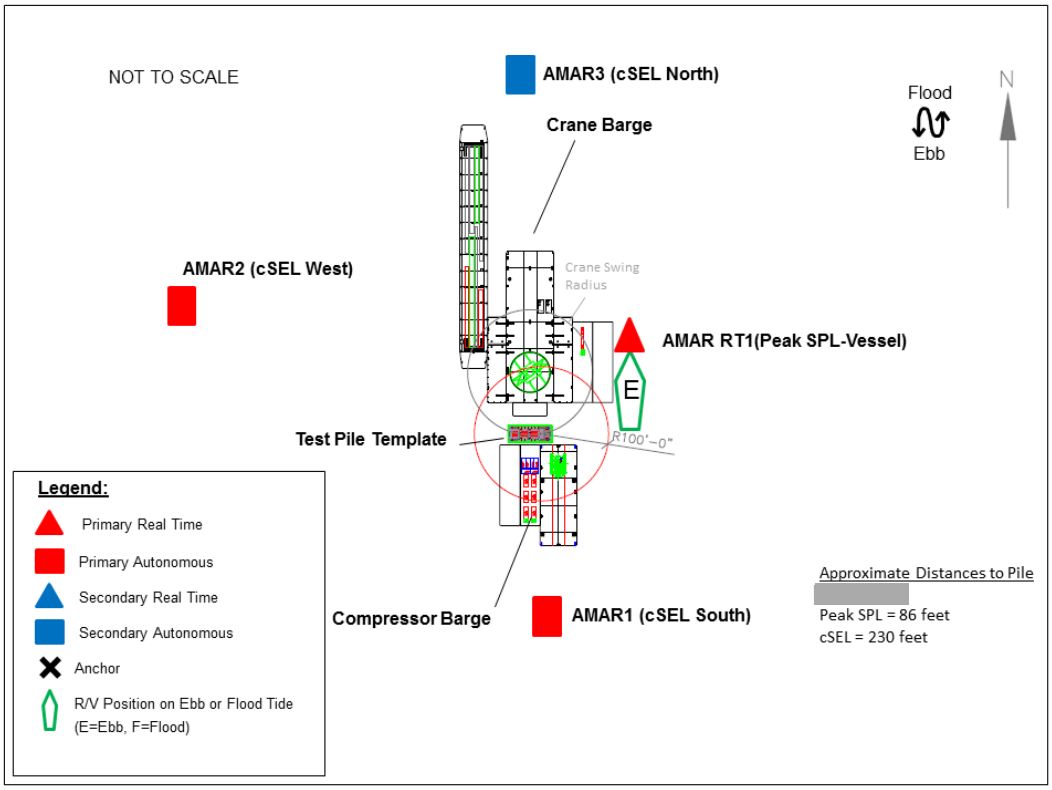

Figure 5. Plan View of a Typical Test Pile Barge Arrangement and Hydrophone Locations for [redacted] piles

Test pile installation for the Design Unit 4 occurred during a variety of current conditions (ebb, flood, and slack currents). Hydrophones (AMARs) were placed to capture data to analyze variation in the performance of the NAS correlated with variation in the river current and barge placement. During the installation of PLT 106 the NAS was tested up-current, down current, and cross-current in 0.8-1.2 knots on the ebb current and 0.3-0.6 knots on the flood current. During the installation of PLT 106P, the NAS was tested down-current and cross-current in 0.2-0.8 knots during the flood current. During the installation of PLT 107P the NAS was tested up-current and cross-current in 0.4-0.0 knots while the current was changing from ebb to slack. During the installation of PLT 107 the NAS was tested down-current and cross-current in 0.8-0.0 knots when the current was changing from flood to slack. Table 2 provides a

summary of the underwater noise monitoring equipment deployment and position relative to the current for the driving of the four test piles.

Table 2. Equipment Deployment and Position Relative to Current for PLT 106, PLT 106P, PLT 107P, and PLT 107

Date Test Pile No.	Hydrophone ID	Location Relative to Pile*	Location Relative to Current	Current During Pile Driving	Distance to Pile (ft)	Water depth (ft)
8/26/2013 PLT 106	AMAR-RT 12	Peak SPL- Vessel	Cross-current	Ebb/ Flood (0.8 – 1.2 knots/ 0.3 – 0.6 knots)	86	7
	AMAR-221	cSEL South	Up-Current, Down-Current		229	10
	AMAR-228	cSEL West	Cross-current		237	10
8/27/2013 PLT 106P	AMAR-RT 11	Peak SPL-Barge	Down-Current	Flood (0.2 – 0.8 knots)	35	12
	AMAR-221	rms SPL West	Cross-Current		461	11
	AMAR-228	rms SPL North	Down-Current		579	11
10/8/2013 PLT 107P	AMAR-RT 11	Peak SPL- Barge	Up-Current	Ebb to slack (0.4 – 0.0 knots)	32	13
	AMAR-175	cSEL North	Up-Current		139	13
	AMAR 228	rms SPL East	Cross-Current		658	12
10/8/2013 PLT 107	AMAR-RT 11	Peak SPL- Barge	Down-Current	Flood to slack (0.8– 0.0 knots)	34	13
	AMAR 175	cSEL North	Down-Current		148	13
	AMAR-228	rms SPL East	Cross-Current		498	12

*Locations correspond to the hydrophone locations labeled in Figure 5 and are based on the following:

- peak SPL – located on the barge or survey vessel, approximately 40 feet from the pile, based on the distance from the pile to the 206 re 1 µPa peak SPL isopleth for [redacted] piles
- cSEL- located approximately 132 feet from the pile, based on the distance from the pile to the 187 dB re 1 μPa^2-s cSEL isopleth for [redacted] piles
- rms SPL – located approximately 400 feet from the pile, based on the distance from the pile to the 150 dB re 1µPa rms SPL for [redacted] piles

The tests for this design unit were informed by previous NAS tests where air flow was varied throughout pile driving but 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 four test piles.

Table 3. Description of NAS during Installation of Test Piles for Design Unit 4

Date Test Pile No.	Water Depth (ft)	Number of Rings	Air Flow (cfm) per Bubbler Ring	Air Pressure (psi)
8/26/2013 PLT 106	9	1	450-2300	10-80
8/27/2013 PLT 106P	12	1	500-1800	20-80
10/8/2013 PLT 107P	13	2	1750-1800	65
10/8/2013 PLT 107	13	2	1750-1800	65

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 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 peak, (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 sound levels measured at each recorder during the test pile installation. Table 5 provides the diameter of the sound level isopleths that serve as the NMFS physiological and behavioral thresholds. **These results show that when the NAS was operational, the diameter of the 206 dB re 1 µPa peak SPL did not exceed NMFS requirement of 40 ft for PLT 106P, PLT 107P and PLT 107 at Design Unit 4.**

The largest diameter of the 206 dB re 1 µPa peak SPL isopleth was 70 ft during PLT 106, which is greater than the 206 dB re 1 µPa peak SPL NMFS requirement of 40-ft [redacted] However, the diameter of the 206 dB re 1 µPA peak SPL isopleth at PLT 106 was calculated with a hydrophone located further than 40 ft, which makes extrapolation to 206 dB re 1 µPA peak SPL isopleth more difficult. As such, the results for PLT 106 are considered unrepresentative of the NAS performance (Attachment 1: Daily Memoranda for Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile Installation PLT 106 for additional detail).

Results from PLTs 106P, 107P, and 107 were as expected, with the width of the 206 dB re 1µPa peak SPL isopleth well within the 40-ft requirement [redacted]. For test piles PLT 106P, PLT 107P, and PLT 107 the largest diameter of the 206 dB re 1 µPa peak SPL isopleth was 20-ft, which is similar to the 206 dB re 1 µPa peak SPL for the NASs tested during the 2012 PIDP. Specifically, during the 2012 PIDP the diameters of the 206 dB re 1 µPa peak SPL isopleth were 15 – 40 ft [redacted] (JASCO 2012)[2].

Furthermore, the estimated diameter of the isopleth at the end of installation of test piles that corresponded to 187 dB re 1 μPa^2-s cSEL never exceeded 290 ft. The river width is approximately 15,000 ft; therefore a fish movement corridor of more than one mile [5,280 ft], which was continuous for more than 1,500 ft, was maintained throughout pile driving, in accordance with NYSDEC Permit Condition 14.

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

Table 4. Measured Sound Levels at Each Recorder During PLT 106, PLT 106P, PLT107P, and PLT 107

Date Test Pile No.	Location*	Max. peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^{2-}s)**
8/26/2013 PLT 106	Peak SPL- Vessel	193	166
	cSEL South	172	147
	cSEL West	177	149
8/27/2013 PLT 106P	Peak SPL- Barge	194	171
	rms SPL West	173	143
	rms SPL North	160	134
10/8/2013 PLT 107P	Peak SPL- Barge	194	198
	cSEL North	180	178
	rms SPL East	153	159
10/8/2013 PLT 107	Peak SPL- Barge	186	197
	cSEL North	168	179
	rms SPL East	162	164

*Locations correspond to the hydrophone locations labeled in Figure 5 and are based on the following:

- peak SPL – located on the barge or survey vessel, approximately 33 feet from the pile, based on the distance from the pile to the 206 re 1 µPa peak SPL isopleth for [redacted] piles
- cSEL- located approximately 132 feet from the pile, based on the distance from the pile to the 187 dB re 1 µPa^2-s cSEL isopleth for [redacted] piles
- rms SPL – located approximately 400 feet from the pile, based on the distance from the pile to the 150 dB re 1µPa rms SPL for [redacted] piles

**At the completion of pile driving.

Table 5. Diameters of Sound Level Isopleths that Represent NMFS Physiological and Behavioral Impact Threshold

Measurement		PLT 106	PLT 106P	PLT 107P	PLT 107
Pile Installation Duration (hh:mm)*		01:02	00:56	00:29**	00:40**
Approximate Diameter (ft) of Isopleth	206 dB re 1 µPa peak SPL	70***	20	14	8
	187 dB re 1 µPa^2-s cSEL	290	235	146	156
	150 dB re 1 µPa rms SPL	546	538	374	468

* Net pile driving times are rounded to the nearest minute.
**Hammer log digital file was corrupted; pile driving time was estimated.
*** Considered unrepresentative of the NAS performance.

4.2.2 NAS Performance

The NAS was tested in flood, ebb, and slack currents with hydrophones located in up-current, down-current, and cross current positions (Table 2). Current speed ranged from 0 to 1.2 knots. Air flow settings ranged from air pressures of 10 to 80 psi and air flows of 450 to 2300 cfm.

For PLT 106, the NAS air pressure was 40–80 psi (900–2300 cfm) during the first phase of installation and 10–70 psi (450–1600 cfm) during the second phase. During the first ½ hour of pile driving (ebb current) sound levels at location Peak SPL Vessel remained fairly steady, despite changes in air pressure; hammer energy remained constant. Conversely, sound levels increased at locations cSEL South and cSEL West during this period. This rise in sound levels began while air pressure was maintained at 80 psi, indicating that it was unrelated to air pressure. Sound levels were higher at all recorders during the second half hour of pile driving (flood current); including while air pressure level was maintained at 70 psi. Sound levels showed very little increase with changes in air pressure from 70 psi to 10 psi despite hammer energy remaining fairly constant during this period. Therefore, it is unlikely that changes in NAS settings are responsible for observed changes in measured sound levels (see Attachment 1: Daily Memoranda for

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile Installation PLT 106 for additional detail).

Estimated peak sound levels extrapolated by linear regression of the measured sound levels during PLT 106 installation exceeded the NMFS threshold of 206 dB re 1 µPa at 20 ft from the pile during both the ebb and flood current (although the sound level was less during the ebb current). It was concluded that this exceedance was related to the hydrophone location relative to the pile driving; not the NAS performance. Specifically, the nearest hydrophone was placed at 86 feet, with the other two hydrophones placed down-current and cross-current at 229 and 237 feet, respectively. We believe the hydrophone arrangement in this case, with the nearest hydrophone at 86 ft, did not properly capture the noise attenuation within the barge spread (i.e., the surrounding barges and pile template) and the subsequent extrapolated 206 dB re 1 µPa radius of 35 ft is misleading, particularly given that it is over 50 ft from the nearest measured (ground-truth data) sound level.

Note that key to the extrapolation approach using linear regression is to have the nearest hydrophone measurement (ground-truth data range) as close as possible to the expected extrapolated range, otherwise the extrapolation can be invalid. The underwater sound measurements during installation of PLT 106P provide evidence for this. Conditions during the installation of PLT 106P were similar to PLT 106 with regard to general river conditions and hammer energies, but here the nearest hydrophone was placed 35 ft (vs. 86 ft at PLT 106) from the pile. Including this one value with the three measurements from PLT 106 in the regression gives a revised extrapolated 206 dB re 1 µPa peak SPL isopleth of approximately 26 ft or an extrapolated radius of 13 ft which is now about 20 ft from the nearest hydrophone measurement. Furthermore, adding the two additional measurements from the installation of PLT106P, at ranges of 461 and 579 ft, does not change this revised extrapolated peak SPL isopleth for PLT 106.

For PLT 106P, the NAS air pressure was 80-55 psi (1800–1100 cfm) during the first phase of pile installation and was 40-20 psi (1200-500 cfm) during the second phase. There was no observable effect on the measured sound levels from changes in the NAS air pressure settings or changes in river currents.

During the installation of PLT 107P, the NAS air pressure remained constant at 65 psi (1750–1800 cfm) for the duration of pile driving. Hammer energies remained constant around 180 kip-ft (± 10 kip-ft) throughout pile driving. There was an increase of approximately 10 dB at locations cSEL North and rms SPL East as the current slowed. This increase occurred while hammer energy and air pressure remained constant over those periods. However, there was no observable effect on the measured sound levels from the change in current at location Peak SPL Barge. As such, there appears to be no correlation with river currents, hammer energy, or NAS settings (Attachment 1: Daily Memoranda for Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile Installation 107P).

For PLT 107 hammer energy remained constant at 180 ± 10 kip-ft and air pressure remained constant at approximately 65 psi, but the currents dropped from 0.8 knots to slack current. The measured sound levels showed different characteristics at each location. Recorded SELss at location Peak SPL Barge remained constant as the pile was driven. However the SELss recorded at locations cSEL North and rms SPL East increased by approximately 15 dB from the start to the end of pile driving. The reason for this increase is unknown as the same trend was not observed at the other hydrophone deployed up-current (Peak SPL Barge). Changes in sound level did not appear to correlate with the river currents, hammer energy or NAS system settings.

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 unconfined multi-tier bubble curtain with bubble rings spaced a maximum of ten feet vertically is effective in minimizing noise in order to meet the NMFS and NYSDEC requirements. Results indicate that the largest estimated width of the 206 dB re 1µPa peak SPL isopleth was measured at 70 ft for the PLT 106 but only 20-ft for the PLT 106P, as compared to the 40 ft predicted by the NMFS BO; these results were considered unrepresentative because of the measurement location. Results from PLTs 106P, 107P, and 107 also indicate that the width the 206 dB re 1µPa peak SPL isopleth was less than 40 ft. These results indicate that the typical size of the 206 dB re 1 µPa isopleths measured for the piles in 10-15 ft of water were similar or smaller than the 206 dB re 1 µPa isopleths measured during 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 290 ft. Therefore, a corridor was maintained where sound levels were less than 187 dB re 1μPa^2·s cSEL. The total length of the corridor was at least one mile (and was continuous for 1,500 feet) across the Hudson River, running east to west.

5.0 NAS Design Plan and Operational Specifications

The installation of the four test piles also demonstrated that the unconfined multi-tier bubble curtain is 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 4, the unconfined multi-tier bubble curtain will be deployed and retrieved in a similar manner to the PLTs 106, 106P, 107P, and 107 pile installations. Based on dredging and armoring, the river bottom at Design Unit 4 will be approximately -11 feet at mean lower low water (MLLW). 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 bubble rings if the water depth greater than 10 feet. Table 6 provides the expected range of water depths at each Design Unit 4 pier and the number of bubble curtain rings to be deployed for pile driving at that pier. The NAS will be deployed according the Construction Work Plan.

Table 6. Range of Water Depths at Each Design Unit 4 Pier and the Number of Bubble Curtain Rings to be Deployed

Pier	Water Depth (feet)	Number of Bubble Curtain Rings*
11	10-12	2
12	10-12	2
13	10-12	2
14	10-12	2
15	10-12	2

*The number of bubble rings at specific piles within a pier is subject to change with approval from the ECM or designee, 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 6),
2. reservoir tank inlet (Figure 7),
3. reservoir tank outlet (Figure 8) 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 ring(s) 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 9).

The following will be checked for each of the piles at each pier within Design Unit 4 (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 starting the compressor.
- 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 6. Valve at the Air Compressor Outlet to the Reservoir Tank

Figure 7. Valve at the Reservoir Tank Inlet

Figure 8. Valve at the Outlet from the Reservoir Tank to the Bubble Curtain

Figure 9. 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 PLT-106 Installation

Daily Memorandum for 26 August 2013

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P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-106 is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 26 August 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) to measure sound levels at ranges of 86–237 ft from the pile (Figure 1 and Table 2). Pile driving occurred between 07:59–10:56 EDT and full ebb current occurred at 08:31 EDT.

One of the autonomous systems was not located during retrieval; therefore, data from two autonomous systems were analyzed for this report.

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-106 activities, 26 August 2013.

Date:	26 August 2013
Pile-Driving Activity	
Test pile identifier:	PLT-106
Pile diameter:	[redacted]
Water depth	9 ft
Hammer type:	Impact (IHC S-280)
Total hammer strikes:	[redacted]
Total penetration:	[redacted]
Net duration of pile driving (hh:mm:ss)	01:02:38
Maximum single strike energy:	125 thousand foot-pounds (kip-ft), (169 kJ)
Total energy transferred:	331,263 kip-ft (449 MJ)
Noise Attenuation System (NAS)	
Single-tier unconfined bubble curtain airflow rate:	450–2300 cubic feet minute (cfm), 10–80 pounds per square inch (psi)
River conditions during pile driving:	Ebb to flood currents 0.8 - 1.2 knots during the ebb (0.4 - 0.6 meters/second [m/s]; Figure 5) 0.3-0.6 knots during the flood(0.2 – 0.3 m/s; Figure 5)

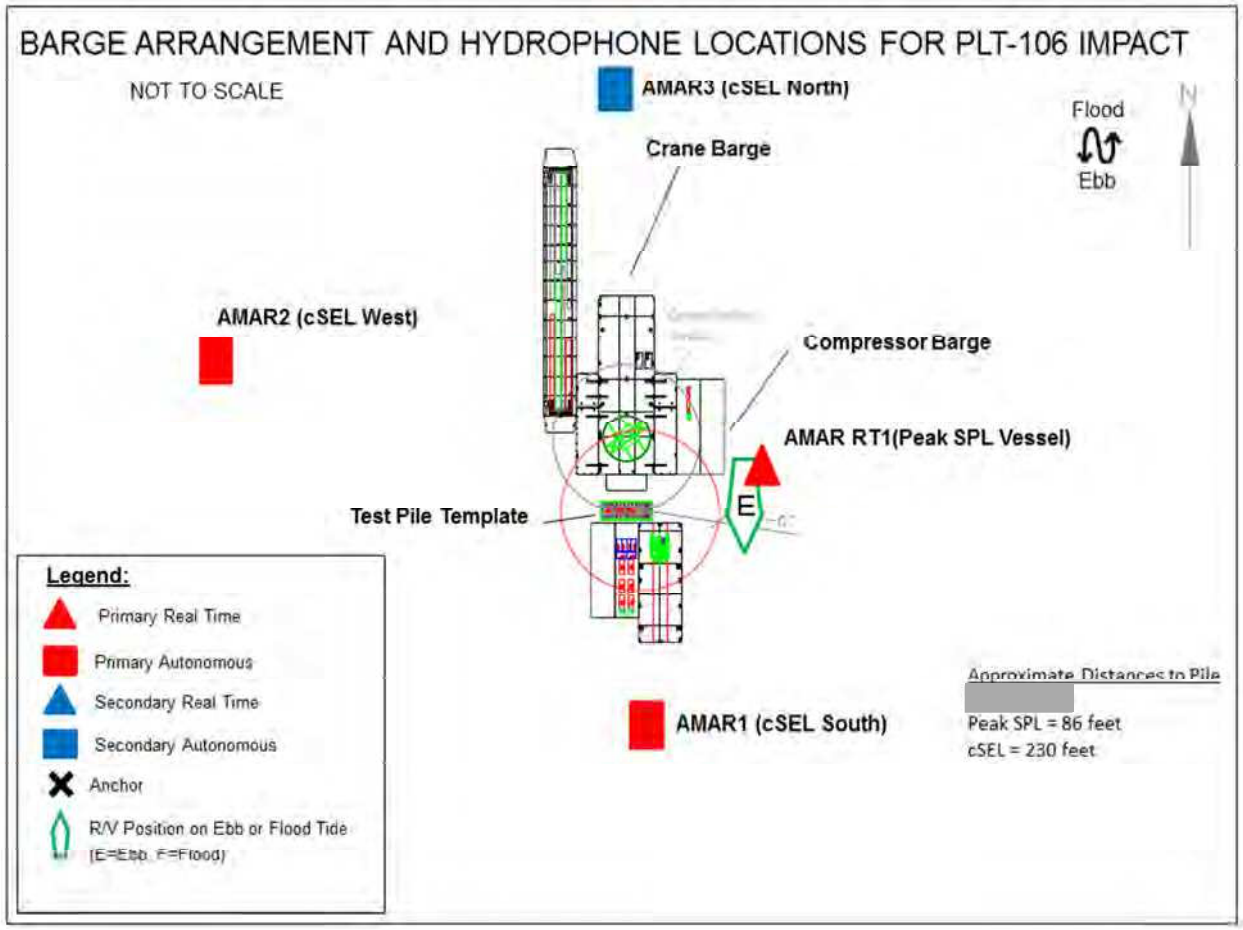


Figure 1. Plan view of pile and barge layout, 26 August 2013, PLT-106.

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 Vessel (cross-current)	AMAR-RT-12	86	7	193	166
cSEL South (down-current/up-current)	AMAR-221	229	10	172	147
cSEL West (cross-current)	AMAR-228	237	10	177	149
cSEL North** (down-current)	AMAR-222	n/a	n/a	n/a	n/a

* 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.

** Recorder not retrieved.

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 indicated that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was approximately 70 ft (extrapolated radius 35 ft.) and thus exceeded the NMFS criteria of a diameter of 40 ft [redacted] piles. It was concluded that this exceedance was related to the location of the hydrophones relative to the pile driving, because no measurements were taken inside the barge spread. Specifically, the nearest hydrophone was placed at 86 feet and the other two hydrophones were placed down-current and cross-current at 229 and 237 feet, respectively. We believe the hydrophone arrangement in this case, with the nearest hydrophone at 86 ft, did not properly capture the attenuation properties within the barge spread. As such, the subsequent extrapolated radius of 35 ft is misleading, given that it is 50 ft from the nearest ground-truth data range of 86 ft.

Note that key to this extrapolation approach, involving a linear regression, is to have the nearest hydrophone measurement location (ground-truth data range) close to the expected extrapolated range, otherwise the extrapolation can be invalid. The underwater sound measurements for the installation of PLT 106P provide evidence for this. Conditions during the installation of PLT 106P were similar to PLT 106 with regard, general river conditions and hammer energies. Here, the nearest hydrophone range was 35 ft, and upon including this one value with the 3 measurements from test 106 in the regression gives a revised extrapolated 206 dB re 1 µPa peak SPL isopleth of approximately 26 ft based on extrapolated radius of 13 ft which is now about 20 ft from the nearest ground-truth data range. Furthermore, adding the two additional measurements from the installation of PLT106P, at ranges of 461 and 579 ft, does not change this revised extrapolated peak SPL isopleth for PLT 106. The hydrophone arrangement for the installation of all other test piles included a measurement at 33 ft, providing a better spread of data and more accurate results.

The diameter of the 187 dB re 1 $\mu Pa^2 \cdot s$ cumulative sound exposure level (cSEL) isopleth was estimated to be 290 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 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	70
187 dB re 1 µPa^2·s cSEL*	290
150 dB re 1 µPa rms SPL (1 s integration time)	546

* At the end of pile driving

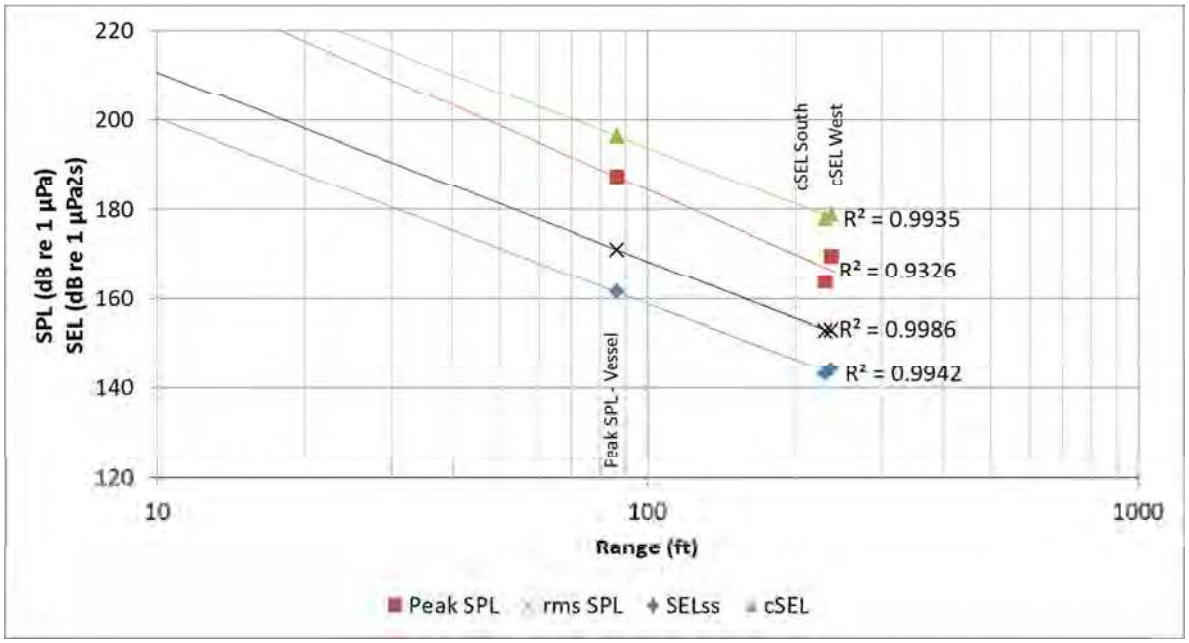


Figure 2. Regression based on mean values of the peak SPL, rms SPL, SELss and cSEL from each recorder from pile driving of Test Pile PLT-106, 26 August 2013. Peak SPL, rms SPL and SELss are instantaneous values. The cSEL represents total sound energy measured during the pile driving.

1.3. Observations

The hammer energy during pile driving at PLT-106 was nearly constant at 108 - 125 kip-ft (Figure 3, Figure 4). NAS air pressure and airflow settings were varied throughout the driving of PLT-106 (Figure 3, Table 6). The first ½ hour of pile driving occurred during ebb current, with measured river currents of 0.8-1.2 knots (Figure 3, Figure 5). The second ½ hour of pile driving occurred during the beginning of the flood current, with measured river currents of 0.3-0.6 knots (Figure 3, Figure 5).

It is unlikely that changes in NAS settings are responsible for the changes in measured sound levels. During the first ½ hour of pile driving (ebb current) sound levels at location Peak SPL Vessel remained fairly steady, despite changes in air pressure and hammer energy remaining constant. Conversely, the sound levels at locations cSEL South and cSEL West rose during this period. This rise in sound levels began when air pressure was maintained at 80 psi, demonstrating that it was unrelated to air pressure (Figure 3). Sound levels were higher at all recorders during the second half hour of pile driving(flood current) even while air pressure levels were maintained at 70 psi. Sound levels showed very little increase with changes in air pressure from 70 psi to 10 psi despite hammer energy remaining fairly constant during this period (Figure

4). Location cSEL South was down current of the pile during ebb current, and up current during the flood current. Location cSEL West was cross current (Figure 1).
Regressions of the measured sound levels exceeded the NMFS threshold of 206 dB re 1 µPa during both periods (Table 4). Although the exceedance was less during the ebb current.

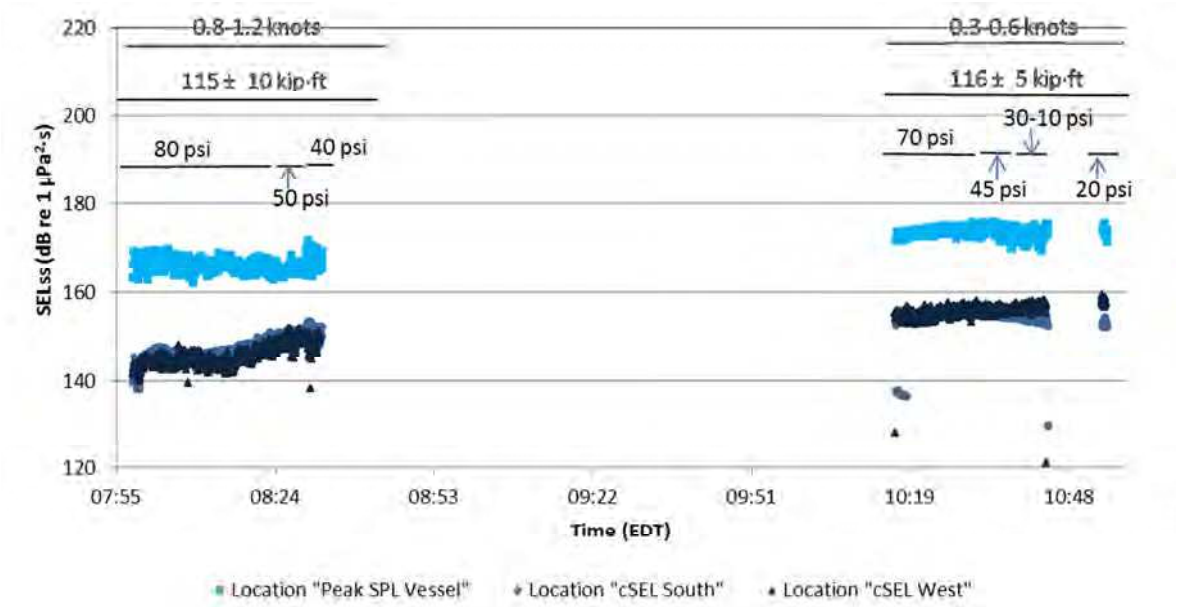


Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots)

Table 4. Estimated isopleth diameters for the NMFS physiological and behavioral thresholds during during the ebb current (07:59 – 08:30) and flood current (10:20 – 11:00).

Criteria	Estimated mean diameters (ft) during ebb current	Estimated mean diameters (ft) during flood current
206 dB re 1 µPa peak SPL	48	81
187 dB re 1 µPa^2·s cSEL*	226	322
150 dB re 1 µPa rms SPL (1 s integration time)	406	626

* At the end of pile driving, assuming 3025 strikes

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 5 provides activities for 26 August 2013.

Table 5. JASCO and construction activities for 26 August 2013.

Time (EDT)	Activity
07:15	Leave dock for job site
07:30	Arrive at barge
07:37	Deploy location cSEL South
07:40	Deploy location cSEL North
07:43	Deploy location cSEL West
07:57	Deploy AMAR-RT
07:59	Start hammering
09:09	Cast CTD
10:55	Stop pile driving
11:09	Begin retrieval of JASCO equipment
12:45	All work complete

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Single-tier unconfined bubble curtain

NAS settings: 450–2300 cfm, 10–80 psi

Table 6. NAS Setting recorded during pile driving at PLT-106, 26 August 2013.

Time (EDT)	Volume/min (cfm)	Pressure (psi)
7:59–8:18	2000–2300	80
8:18–8:27	1200–1300	50
8:27–8:33	900–1000	40
10:17–10:27	1500–1600	70
10:27–10:35	1100–1200	45
10:35–10:39	750–850	30
10:39	450–500	10
10:55–10:56	750–800	20

2.2.2. Impact Hammering Log

Total energy: 331,263 kip-ft (449 MJ)

Total number of strikes:

Maximum per-strike energy: 125 kip-ft (169 kJ)

Net pile driving duration (hh:mm:ss): 01:02:38

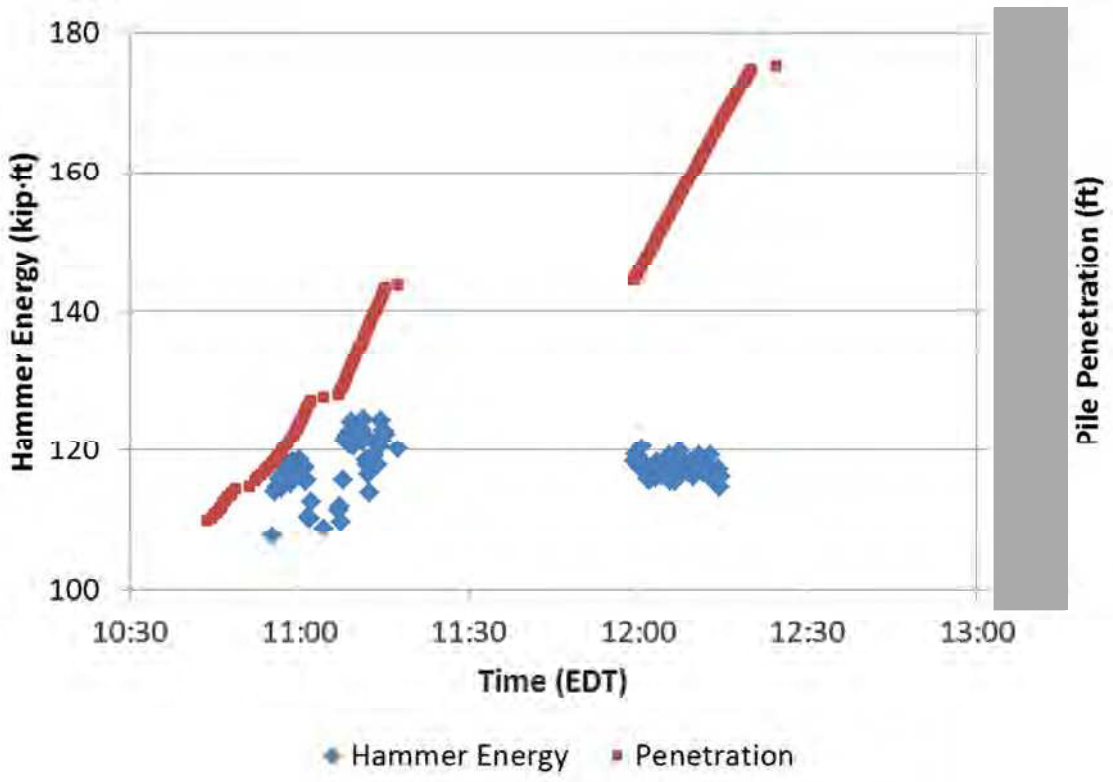


Figure 4. Hammer energy (kip-ft) and pile penetration (ft) during pile driving of PLT-106, 26 August 2013.

3. Weather and River Conditions

Table 7 provides the predicted currents at the project site on 26 August 2013. Figure 5 provides the ADCP-measured currents. Figure 6 provides the speed of sound in water, based on salinity and temperature measured using the CTD.

Table 7. Weather conditions, and predicted local current times.

Weather conditions:	Cloudy, sea state 1–2, wind 1–3 kts from south
Full ebb current:	08:31 EDT (1.8 kts)
Slack current:	11:33 EDT
Full flood current:	14:50 EDT (1.1 kts)

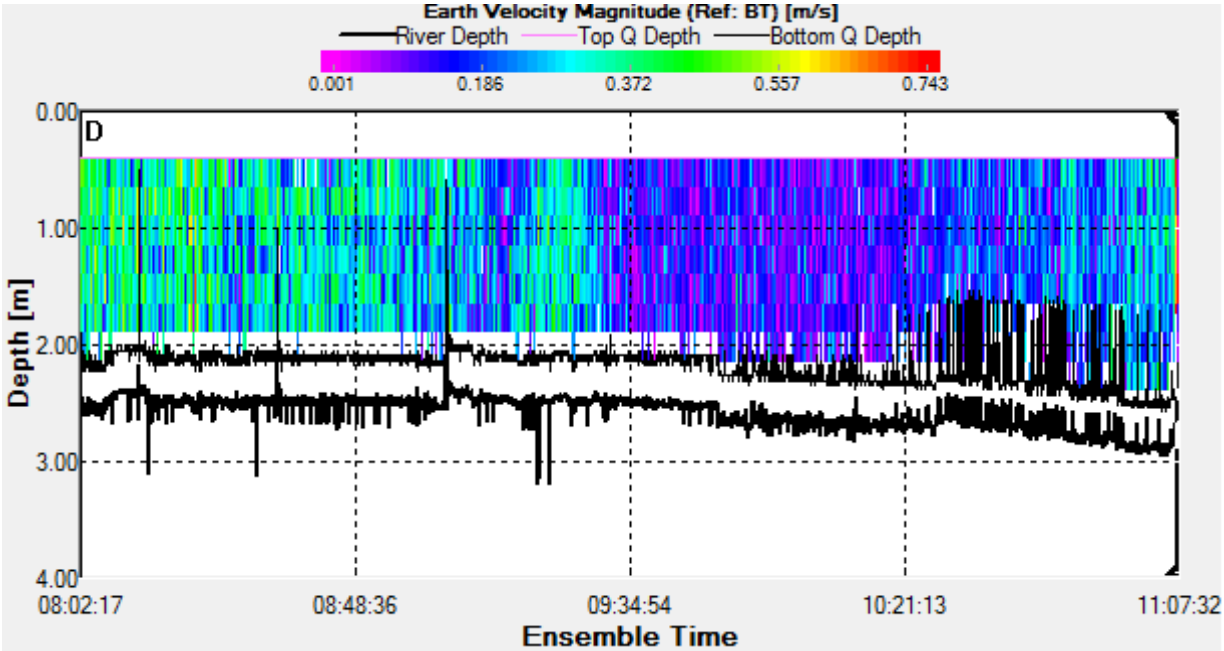


Figure 5. ADCP data from 26 August 2013 taken from the Alpine vessel located at Peak SPL Vessel (41.071300 N, 73.907376 W), times are in EDT.

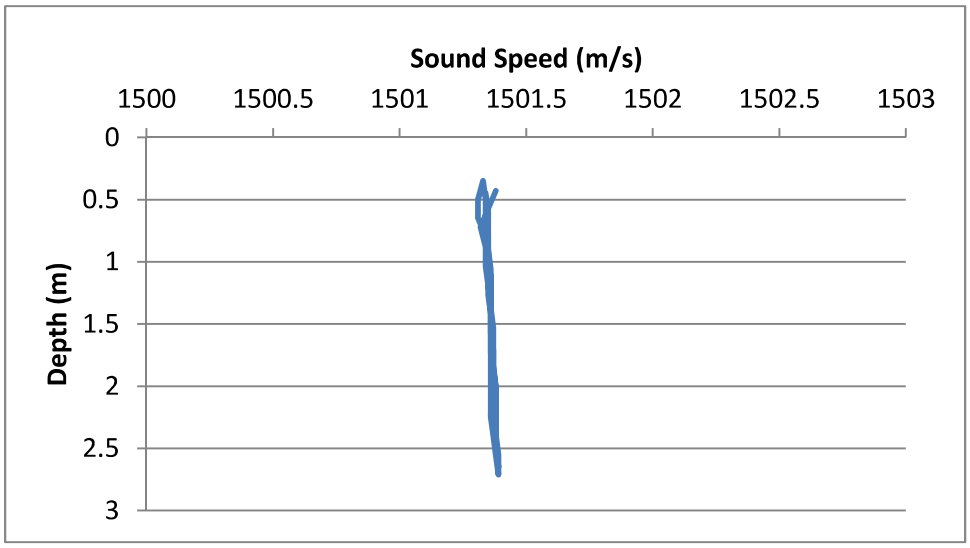


Figure 6. CTD Cast performed at 09:09 (EDT at location Peak SPL Vessel (41.071300 N, 73.907376 W).

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 8 provides information on the real-time monitoring equipment used on 26 August 2013. Table 9 provides location information on the real-time recorders

Table 8. Real-time monitoring equipment for Test Pile PLT-106, 26 August 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-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 9. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 26 August 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time	Water Depth (ft)	Distance to Pile (ft)
Peak SPL, Vessel	AMAR-RT-12	41.071300	73.907376	07:57	7	86

4.2. Autonomous Monitoring Equipment

Table 10 provides information on the autonomous monitoring equipment used on 26 August 2013. Table 11 provides the locations of the autonomous recorders.

Table 10. Autonomous recording equipment for Test Pile PLT-106, 26 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:	-199.8 dB re 1 V/µPa	1
AMAR-222 sensitivity:	n/a (not retrieved)	1
AMAR-228 sensitivity:	-199.7 dB re 1 V/µPa	1

Table 11. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations 26 August 2013

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time	Water Depth	Distance to Pile (ft)
cSEL South (up-current)	AMAR-221	41.07056	73.90773	07:37	10	229
cSEL West (cross-current)	AMAR-228	41.07124	73.90850	07:43	10	237
cSEL North (down-current)	AMAR-222	n/a	n/a	07:40	10	n/a*

Appendix A. Pile Driving Plots

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

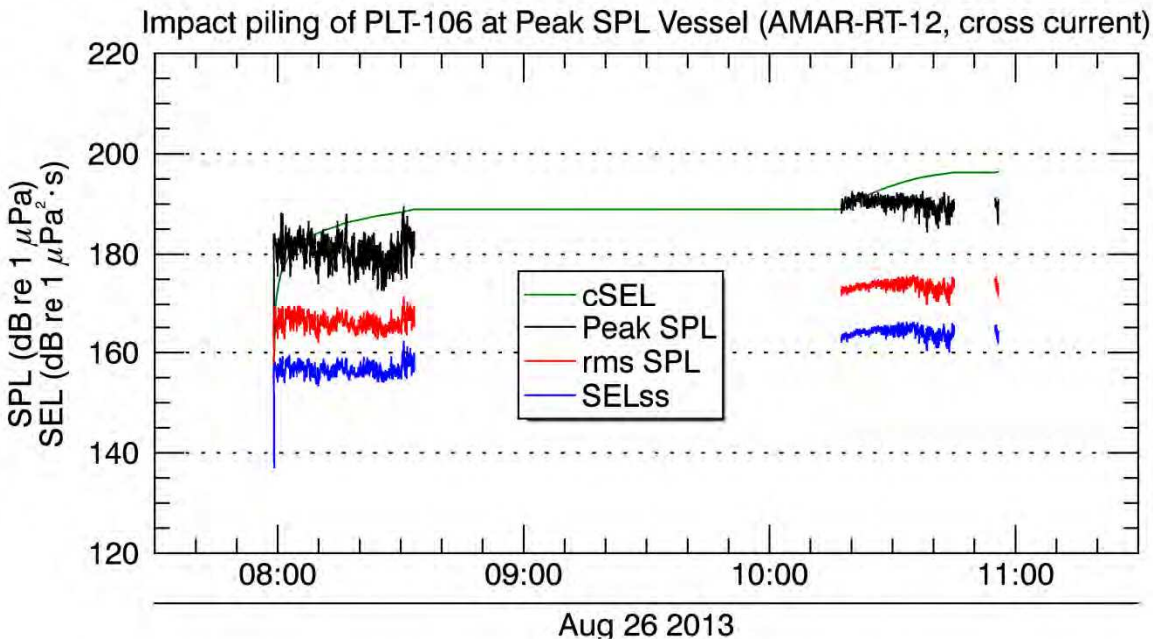


Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-106 measured 86 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

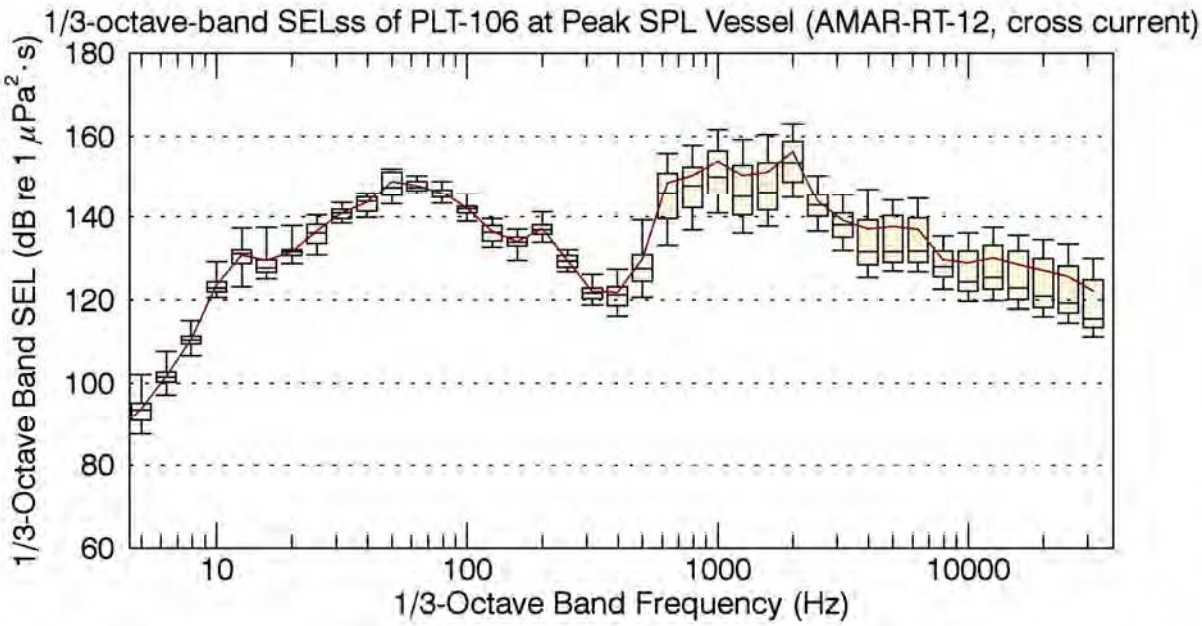


Figure 8. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-106 measured 86 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). 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-106 measured 86 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 uPa^2·s)
L_{max}	192.6	175.9	166.2
L_5	191.4	174.7	165.1
L_{25}	190.1	173.6	164.0
L_{50}	184.2	168.2	158.4
L_{75}	180.7	165.8	156.4
L_{95}	177.2	164.2	155.1
L_{mean}	187.5	171.2	161.6

* 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 cSEL South

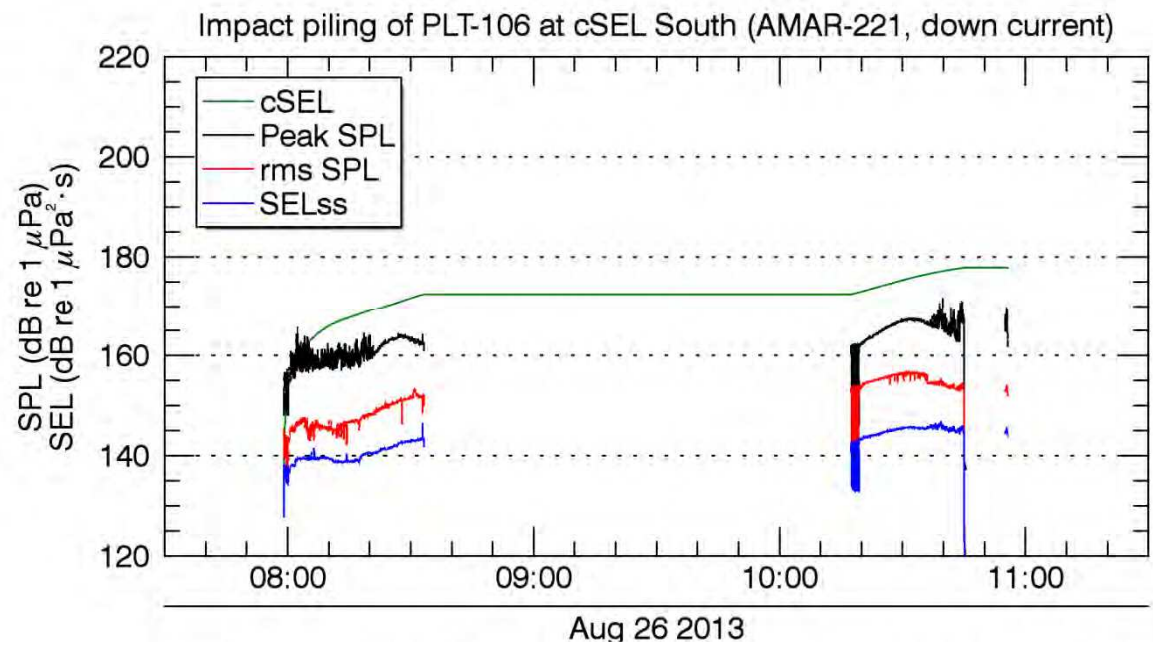
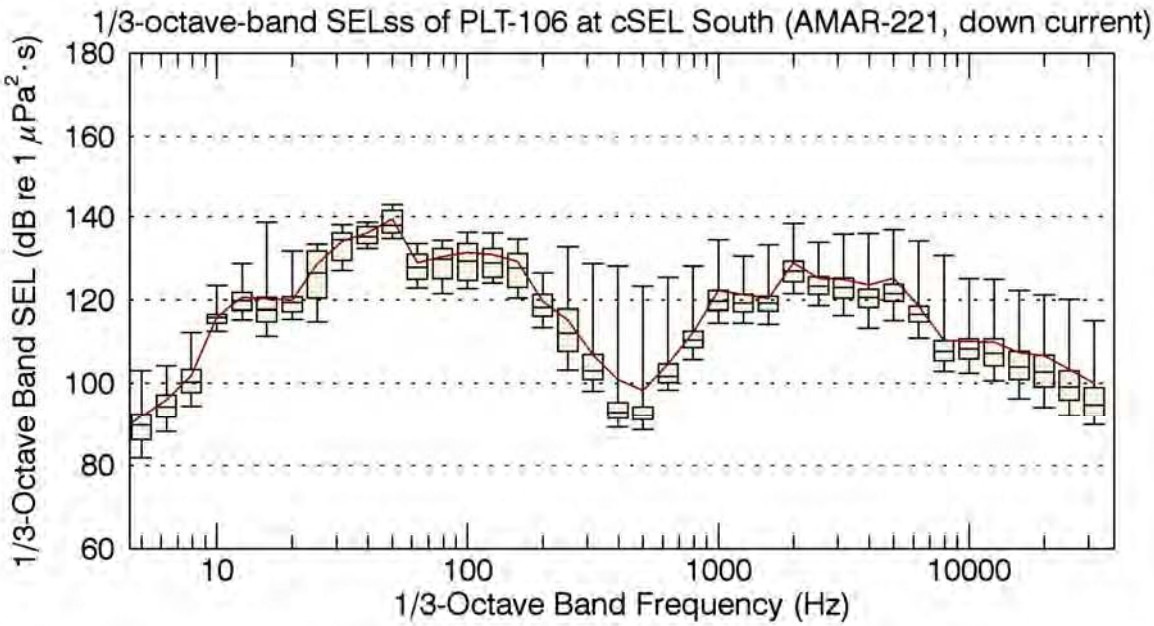


Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-106 measured 229 ft from the pile at location cSEL South using AMAR-221. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.



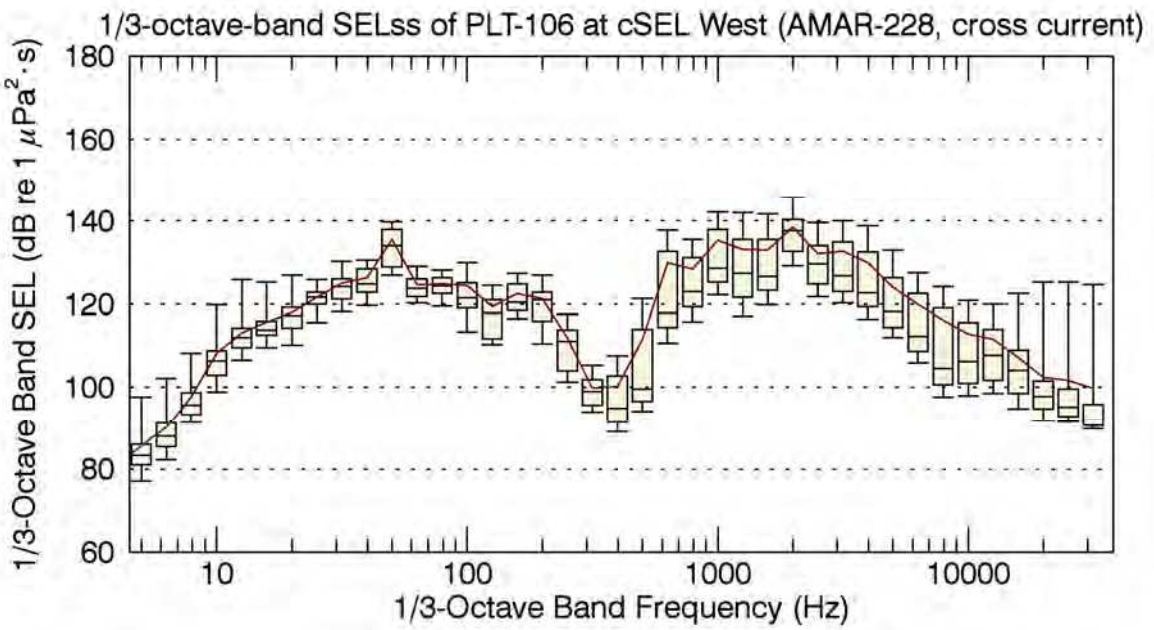


Figure 10. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-106 measured 229 ft from the pile at location cSEL South using AMAR-221. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). 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-106 measured 229 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 uPa^2·s)
L_{max}	171.8	156.8	146.9
L_5	167.3	156.5	145.7
L_{25}	165.9	154.7	145.2
L_{50}	163.1	151.8	142.9
L_{75}	160.3	146.9	139.5
L_{95}	157.5	144.8	138.7
L_{mean}	164.0	152.8	143.2

* 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.3. Impact Pile-Driving Sound Levels from cSEL West

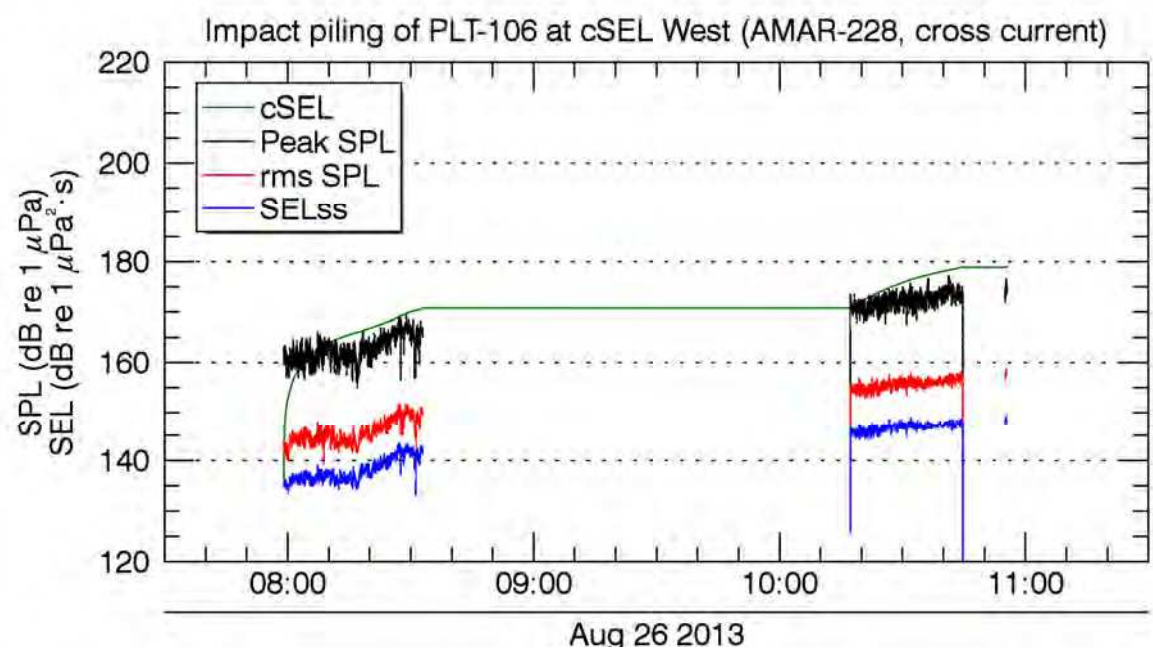


Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-106 measured 237 ft from the pile at location cSEL West using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

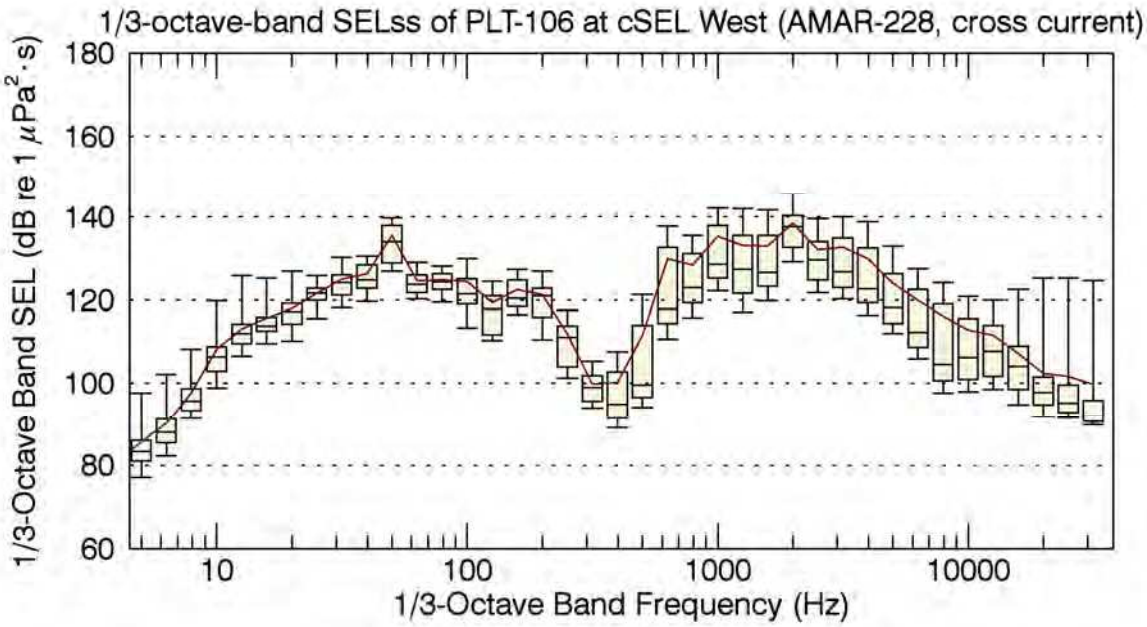


Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-106 measured 237 ft from the pile at location cSEL West using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).Figure A. 1. Distribution of one-second 1/3-Octave rms SPLs measured 237 ft from Test Pile PLT-106 on AMAR-228.

Table 14. Sound levels for the pile driving of Test Pile PLT-106 measured 227 ft from the pile at location cSEL West using AMAR-228.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 uPa^2·s)
L_{max}	177.3	158.8	149.3
L_5	174.1	156.9	147.8
L_{25}	172.1	155.6	146.8
L_{50}	166.5	149.7	141.8
L_{75}	162.2	144.9	137.1
L_{95}	159.2	142.7	135.4
L_{mean}	169.7	153.0	144.2

* 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}).

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 106P Installation

Daily Memorandum for 27 August 2013

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7 March 2014

P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-106P is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 27 August 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 35–579 ft from the pile (Figure 1 and Table 2). Pile driving occurred between 14:40–16:25 Eastern Daylight Time (EDT). Slack current occurred at 12:24 EDT and full flood current occurred at 15:41.

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-106P activities, 27 August 2013.

Date:	27 August 2013
Pile-Driving Activity	
Test pile identifier:	PLT-106P
Pile diameter:	[redacted]
Water depth:	12 ft
Hammer type:	Impact (IHC S-280)
Total hammer strikes:	[redacted]
Total penetration:	[redacted]
Net duration of pile driving (hh:mm:ss):	00:55:46
Maximum single strike energy:	126.9 thousand foot-pounds (kip-ft), (172 kJ)
Total energy transferred:	325,031 kip-ft (441 MJ)
Noise Attenuation System (NAS)	
One-tier unconfined bubble curtain, airflow rate:	500–1800 cubic feet minute (cfm), 20 - 80 pounds per square inch (psi)
River conditions during pile driving:	flood current 0.2–0.8 knots (0.1–0.4 meters per second [m/s] depth dependent; Figure 5)

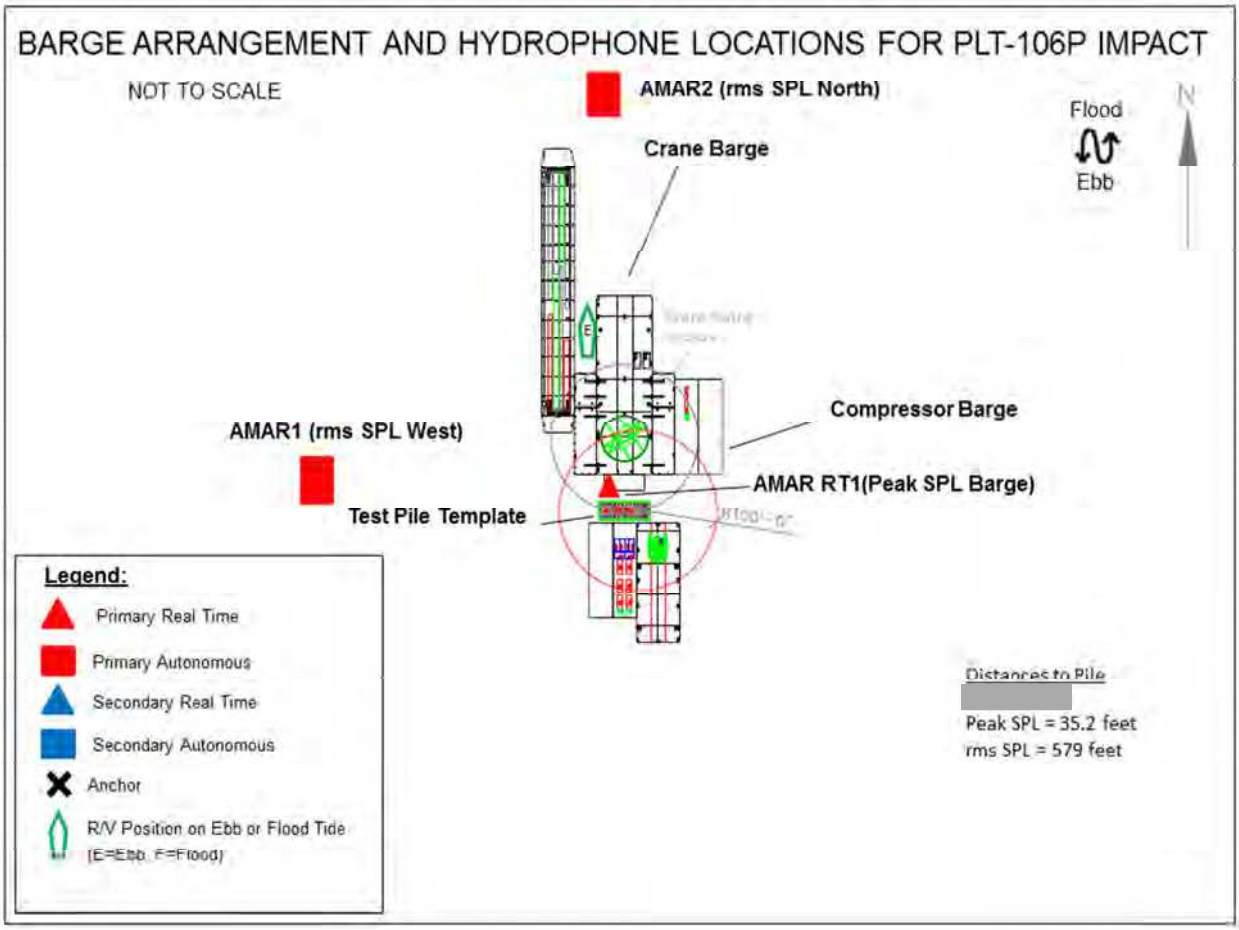


Figure 1. Plan view of pile and barge layout, 27 August 2013, PLT-106P.

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 (down-current)	AMAR-RT-11	35	12	194	171
rms SPL West (cross-current)	AMAR-221	461	11	173	143
rms SPL North (down-current)	AMAR-228	579	11	160	134

* 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 20 ft, and did not exceed NMSF criteria of a diameter of 40 ft for [redacted] piles. The diameter of the 187 dB re 1 µPa^2·s sound exposure level (cSEL) isopleth was estimated to be 235 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 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	20
187 dB re 1 µPa^2·s cSEL*	235
150 dB re 1 µPa rms SPL (1 s integration time)	538

* At the end of pile driving

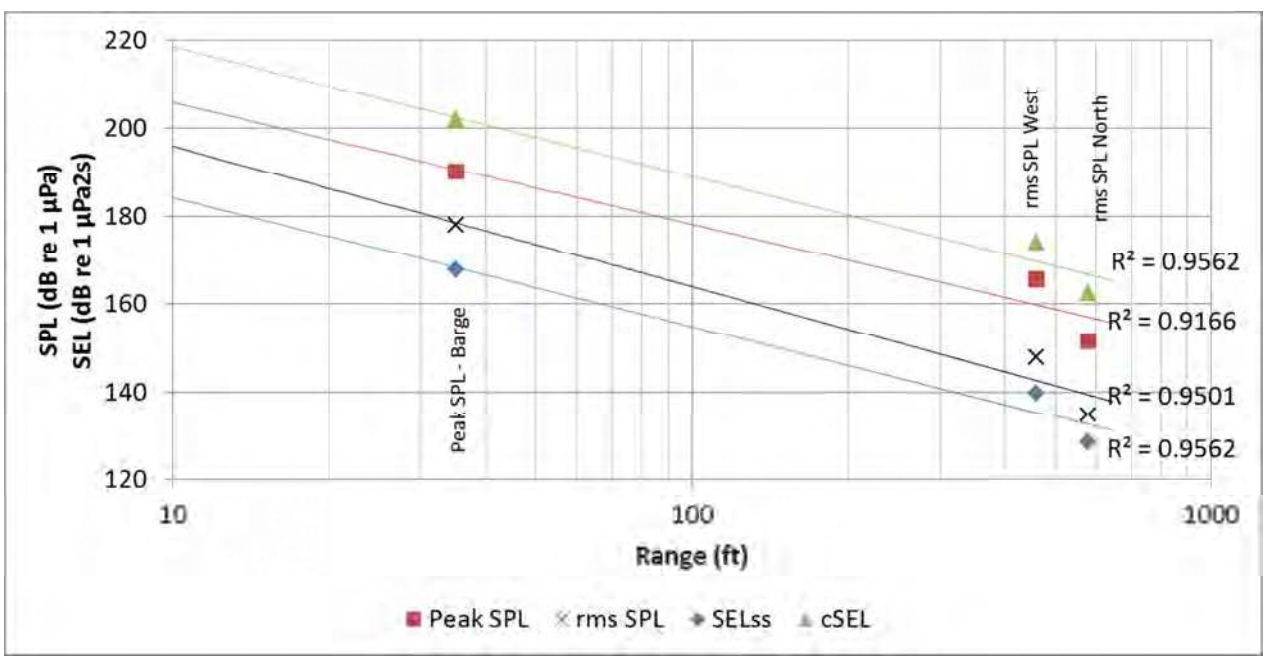


Figure 2. Regression based on mean values of the SELss, peak SPL, cSEL, and rms SPL from each recorder from pile driving of Test Pile PLT-106P, 27 August 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents total sound energy measured during the pile driving.

1.3. Observations

The hammer energy during pile driving at PLT-106P was nearly constant at 125 kip-ft (Figure 3, Figure 4). The NAS air pressure and airflow decreased throughout the pile driving, starting at 80 psi and finishing at 20 psi (Figure 3, Table 5). The majority of the pile driving occurred during the flood tide, with an approximate average current of 0.5 to 0.8 knots (Figure 3, Figure 6). There was no observable effect on the measured sound levels from changes in the NAS air pressure settings or changes in river currents (Figure 3).

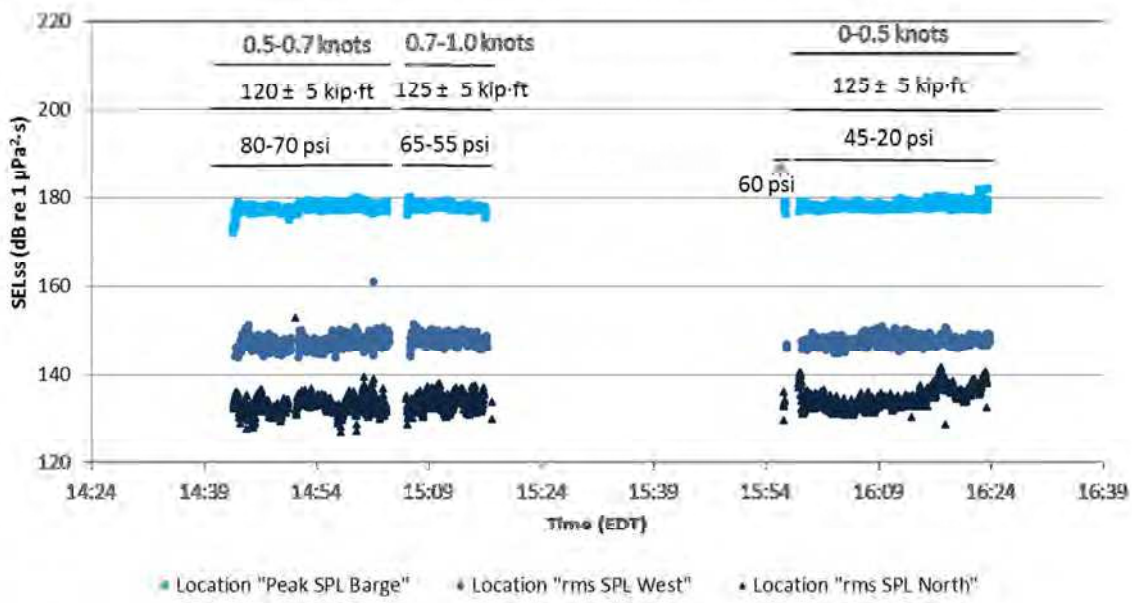


Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 03 August 2013.

Table 4. JASCO and construction activities for Test Pile PLT-106P, 27 August 2013.

Time (EDT)	Activity
10:21	Safety meeting on shore.
10:59	Leave dock for job site
11:25	Head to Hudson River Harbor (Sea State at 3-4ft, Alpine states too rough for deployment)
11:33	Transit to barge spread for AMAR-RT deployment
12:59	Deploy AMAR-RT from barge
13:16	Pick up hammer
14:30	Deploy all autonomous AMARs (Alpine crew)
14:41	Hammer in place, test NAS
14:43	Begin pile driving
15:16	Stop pile driving to install pile monitoring equipment
15:56	Restart pile driving
16:24	Stop pile driving, pack equipment
16:54	Transfer to Alpine vessel
17:01	Cast CTD
17:02	Begin AMAR retrieval
17:24	Alpine vessel at dock
17:30	All work completed

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: One-tier unconfined bubble curtain

NAS settings: 500–1800 cfm, 20–80 psi

Table 5. NAS Setting recorded during pile driving at Test Pile PLT-106P, 27 August 2013.

Time (EDT	Volume/min (cfm)	Pressure (psi)
14:43–14:55	1700–1800	80
14:58–15:03	1300–1400	70
15:06–15:14	1250–1400	65
15:15–15:17	1100–1200	55
15:56–15:58	1100–1200	60
16:01–16:08	900–1000	45
16:08–16:15	700–800	30
16:15–16:24	500–550	20

2.2.2. Impact Hammering Log

Total energy: 325,031 kip-ft (441 MJ)

Total number of strikes:

Maximum per-strike energy: 126.9 kip-ft (172 kJ)

Net pile driving duration (hh:mm:ss): 00:55:46

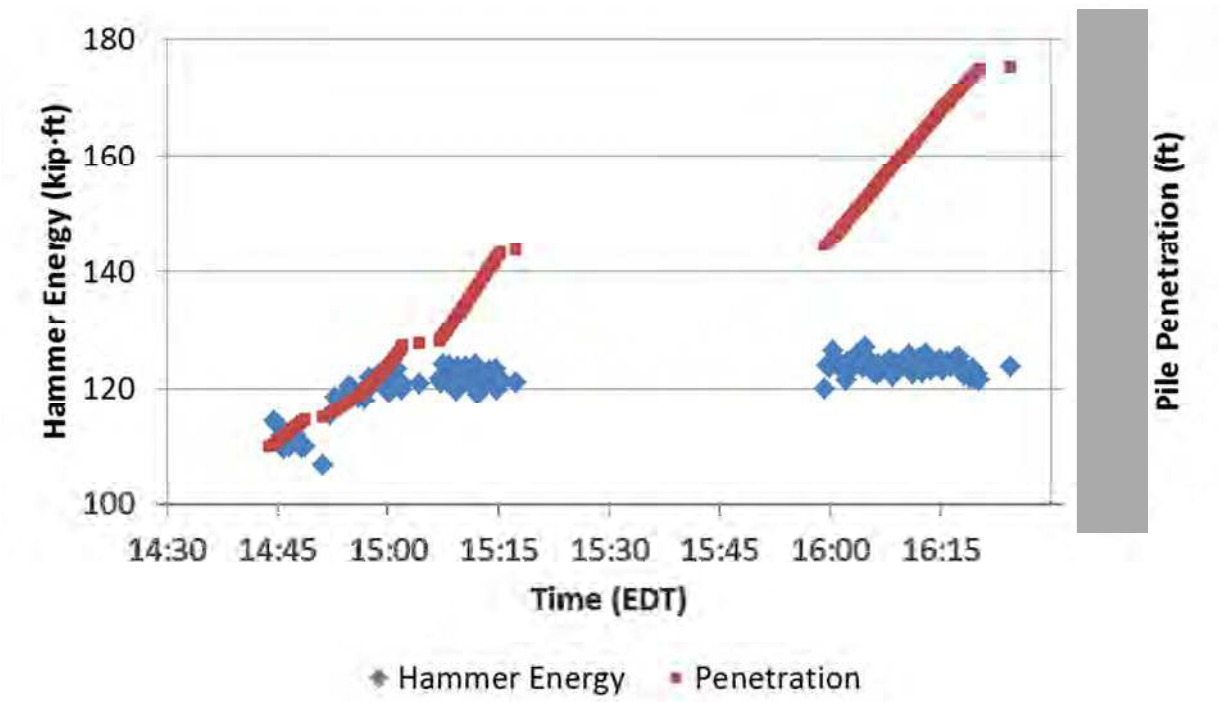


Figure 4. Hammer energy (kip-ft) and pile penetration (ft) for the impact pile driving of PLT-106P, 27 August 2013.

3. Weather and River Conditions

Table 6 and Figure 5 provide the predicted currents at the project site on 27 August 2013. Figure 5 provides the ADCP-measured currents. Figure 6 provides the speed of sound in water, based on salinity and temperature measured using the CTD.

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

Weather conditions:	Sunny, wind N 10–15 knots, Sea 3–4ft, calming to 1–2ft in late afternoon
Full ebb current:	N/A
Slack current:	12:24, 18:28
Full flood current:	15:41 (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=

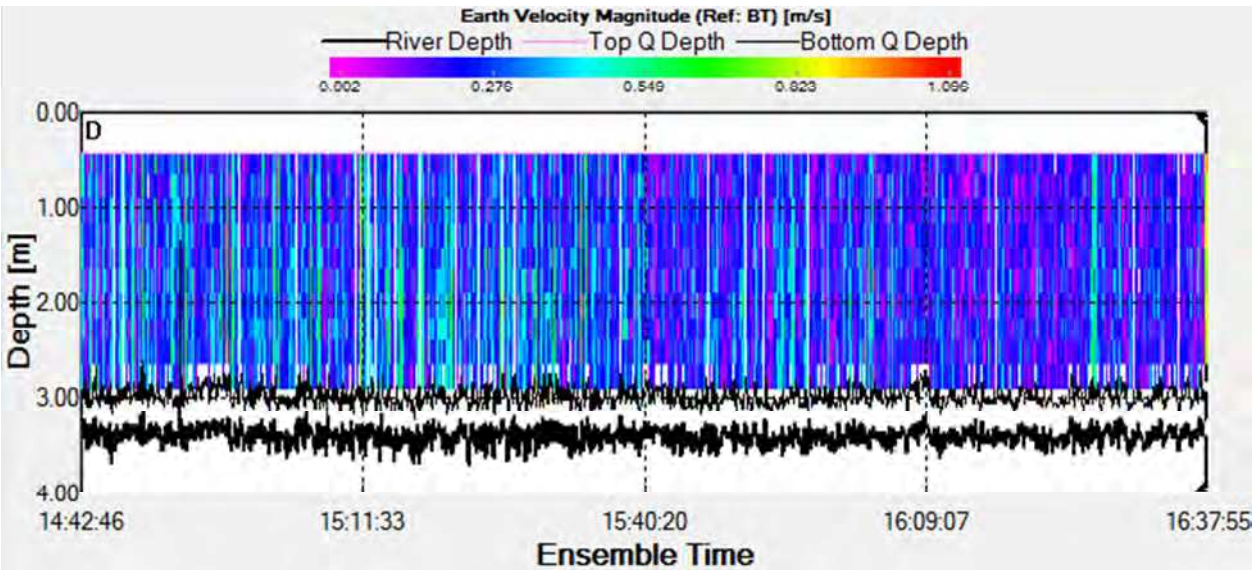
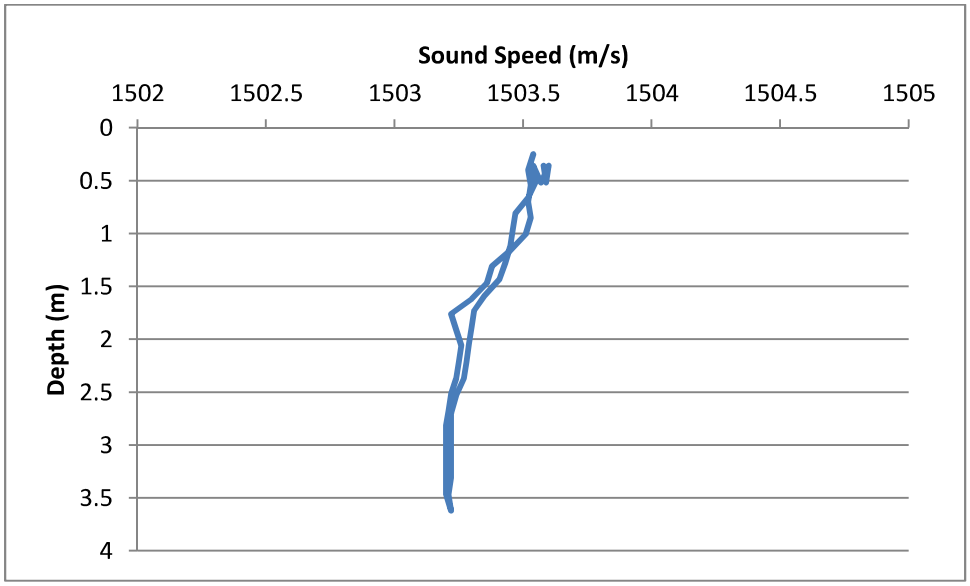


Figure 5. ADCP data from the Alpine vessel, 27 August 2013, times are in EDT.



4. Figure 6. CTD Cast performed at 17:01 (EDT at location rms SPL North (41.07281 N, 73.90784 W).Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 7 provides information on the real-time monitoring equipment used on 27 August 2013.

Table 8 provides location information on the real-time recorders

Table 7. Real-time monitoring equipment for Test Pile PLT-106P, 27 August 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:	-211.1 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, 27 August 2013.

Station	Recorder ID	Latitude	Longitude	Deployment time	Water depth (ft)	Distance to pile (ft)
Peak SPL Barge	AMAR-RT-11	41.07129	-73.9078	12:59	12	35

4.2. Autonomous Monitoring Equipment

Table 7 provides information on the autonomous monitoring equipment used on 27 August 2013. Table 10 provides the locations of the autonomous recorders.

Table 9. Autonomous monitoring equipment for Test Pile PLT-106P, 27 August 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:	-199.7 dB re 1 V/µPa	1
AMAR-228 sensitivity:	-199.6 dB re 1 V/µPa	1

Table 10. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations 27 August 2013

Station	Recorder ID	Latitude	Longitude	Deployment time	Water depth	Distance to pile (ft)
rms SPL West (Cross-current)	AMAR-221	41.07097	-73.90953	14:13	11	461
rms SPL North (Down-current)	AMAR-228	41.07281	-73.90784	14:19	11	579

Appendix A. Pile Driving Plots

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

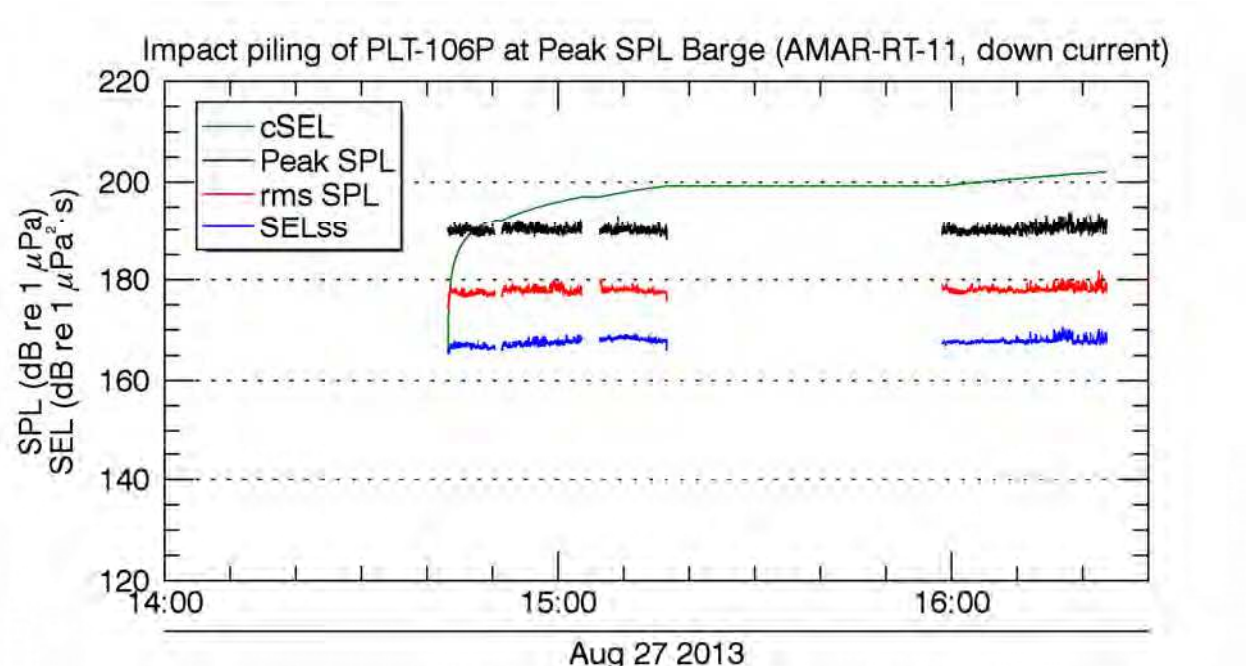


Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-106P measured 35 ft from the pile at location peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

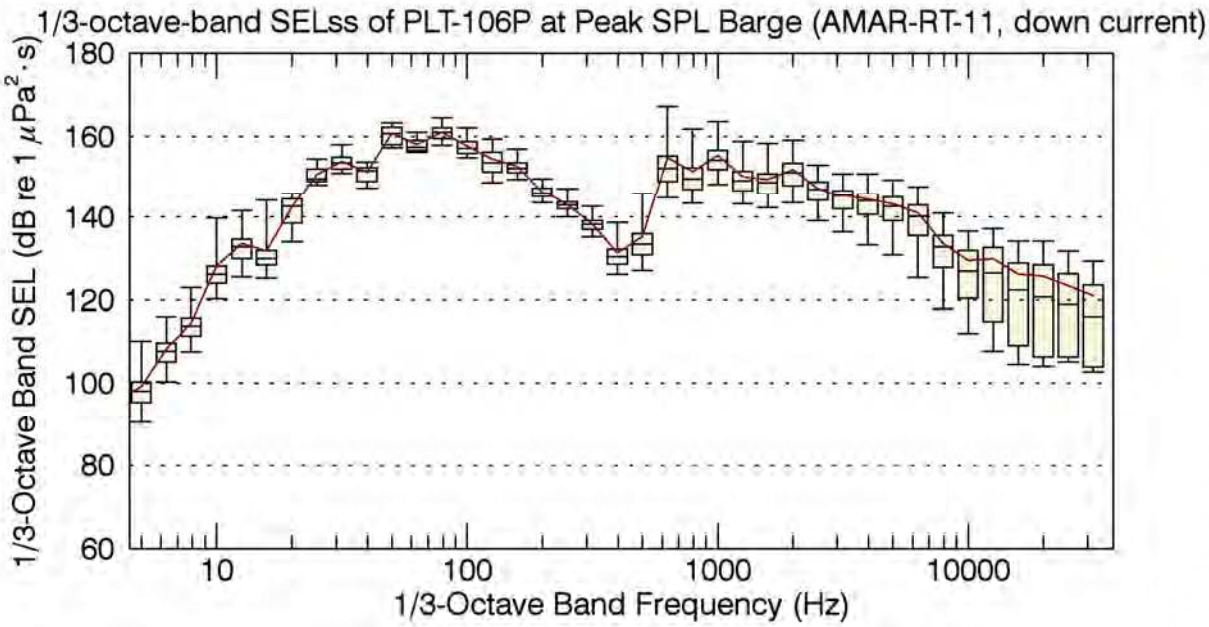


Figure 8. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-106P measured 35 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). 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-106P measured 35 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 µPa²·s)
L_{max}	194.0	181.6	170.7
L_5	191.7	179.1	168.8
L_{25}	190.5	178.2	168.1
L_{50}	190.0	177.8	167.7
L_{75}	189.5	177.5	167.4
L_{95}	189.0	177.0	166.6
L_{mean}	190.2	178.0	167.8

* 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}).

A.2. Impact Pile-Driving Sound Levels from rms SPL West

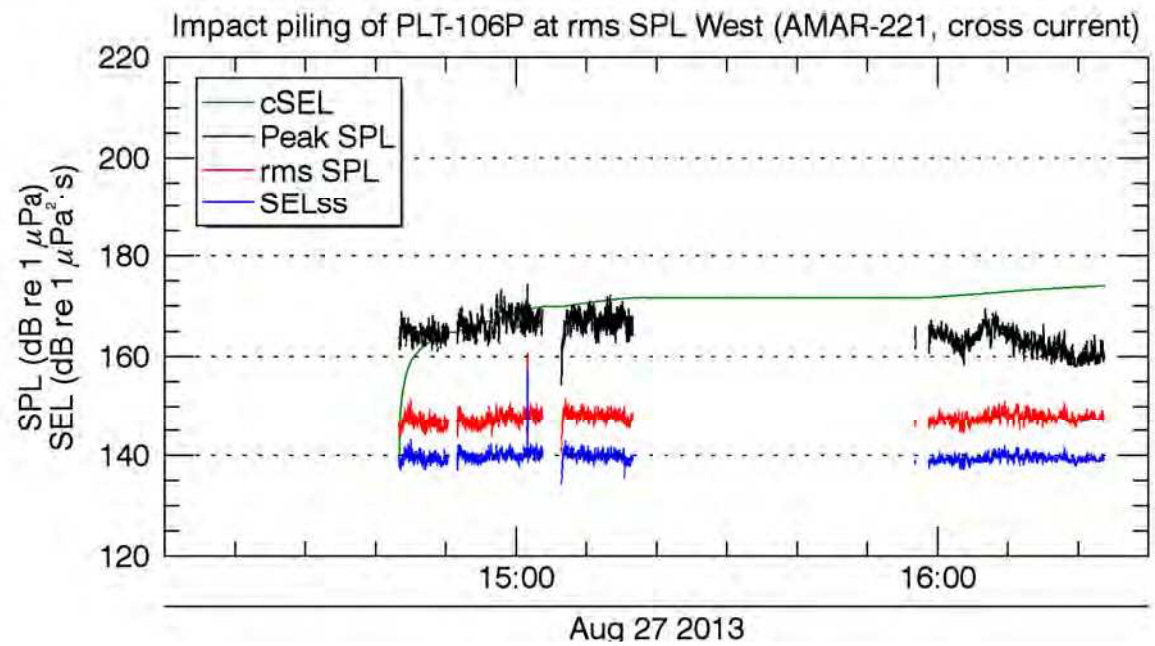


Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-106P measured 461 ft from the pile at location rms SPL West using AMAR-221. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

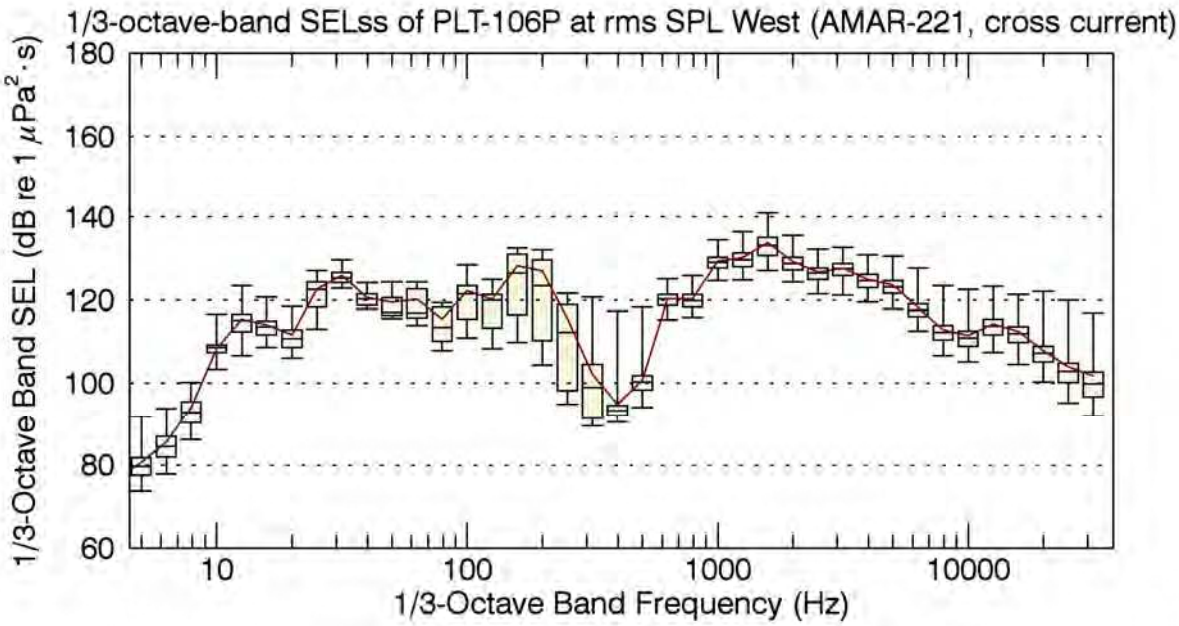


Figure 10. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-106P measured 461 ft from the pile at location rms SPL West using AMAR-221. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 12. Sound levels for the pile driving of Test Pile PLT-106P measured 461 ft from the pile at location rms SPL West using AMAR-221.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa²·s)
L_{max}	173.3	151.5	143.3
L_5	169.3	149.4	141.1
L_{25}	166.8	148.3	140.1
L_{50}	164.8	147.6	139.5
L_{75}	162.8	146.8	139.0
L_{95}	159.4	145.6	138.3
L_{mean}	165.6	147.7	139.7

* 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.3. Impact Pile-Driving Sound Levels from rms SPL North

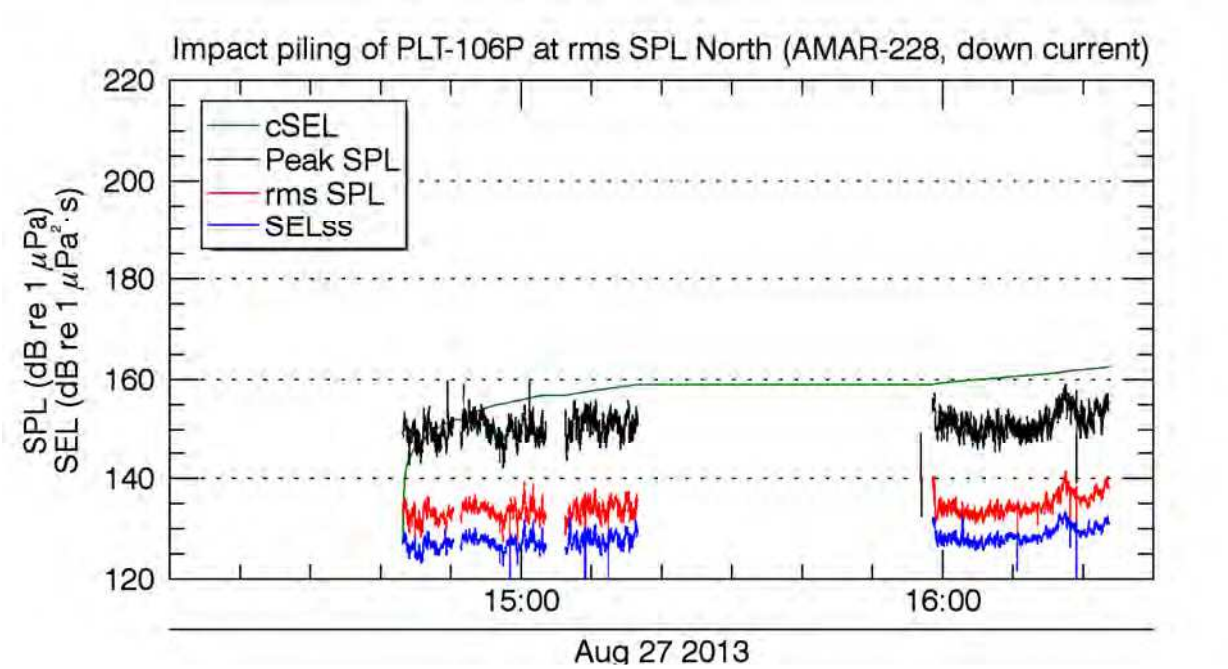


Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-106P measured 579 ft from the pile at location rms SPL North using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

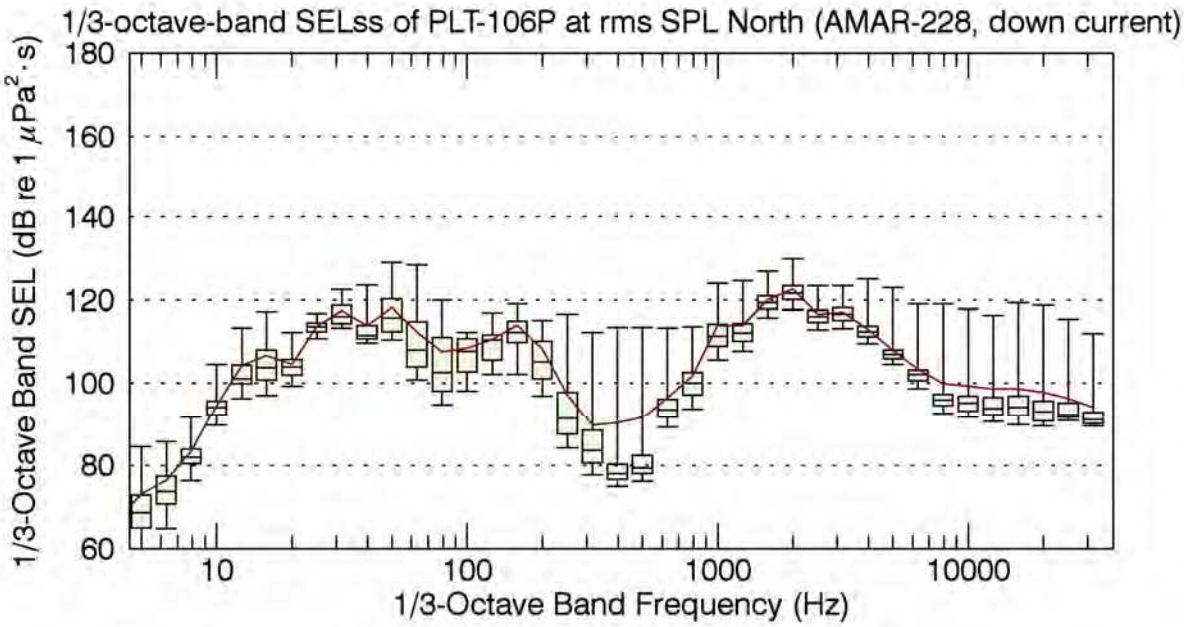


Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-106P measured 579 ft from the pile at location rms SPL North using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 13. Sound levels for the pile driving of Test Pile PLT-106P measured 579 ft from the 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 µPa²·s)
L_{max}	159.9	141.5	133.5
L_5	155.4	137.7	131.1
L_{25}	152.5	135.1	128.9
L_{50}	150.7	133.9	127.8
L_{75}	149.1	132.8	126.9
L_{95}	146.6	131.3	125.5
L_{mean}	151.6	134.6	128.3

* 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}).

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 107P Installation

Daily Memorandum for 08 October 2013

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Authors:
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7 March 2013

P001206-001

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1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-107P is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 08 October 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 32–658 ft from the pile (Figure 1 and Table 2). Pile driving occurred between 08:03–08:32 Eastern Daylight Time (EDT). Ebb current was predicted to occur at 06:15 and slack current occurred at 09:16 EDT; however, ADCP measurements on-site indicated that slack current occurred around 08:30.

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-107P activities, 08 October 2013.

Date:	08 October 2013
Pile-driving activity	
Test pile identifier:	PLT-107P
Pile diameter:	[redacted]
Water depth:	13 ft
Hammer type:	Impact (IHC S-280)
Total hammer strikes:	[redacted]
Total penetration:	[redacted]
Net duration of pile driving (hh:mm:ss):	00:~00:29:00*
Maximum single strike energy:	188.6 thousand foot-pounds (kip-ft), (255 kJ)
Total energy transferred:	290,389 kip-ft, (394 MJ)
Noise Attenuation System (NAS)	
Two-tier unconfined bubble curtain airflow rate:	1750–1800 cubic feet per minute (cfm), 65 pounds per square inch (psi)
River conditions during pile driving:	Ebb to Slack current, 0.4–0 knots current (0.2–0 meters per second [m/s], Table 5 and Figure 5)

*The IHC hammer log file appeared to be corrupted. Approximate pile drive given based on the start and stop of times of pile driving, there were no breaks in active pile driving for PLT 107P.

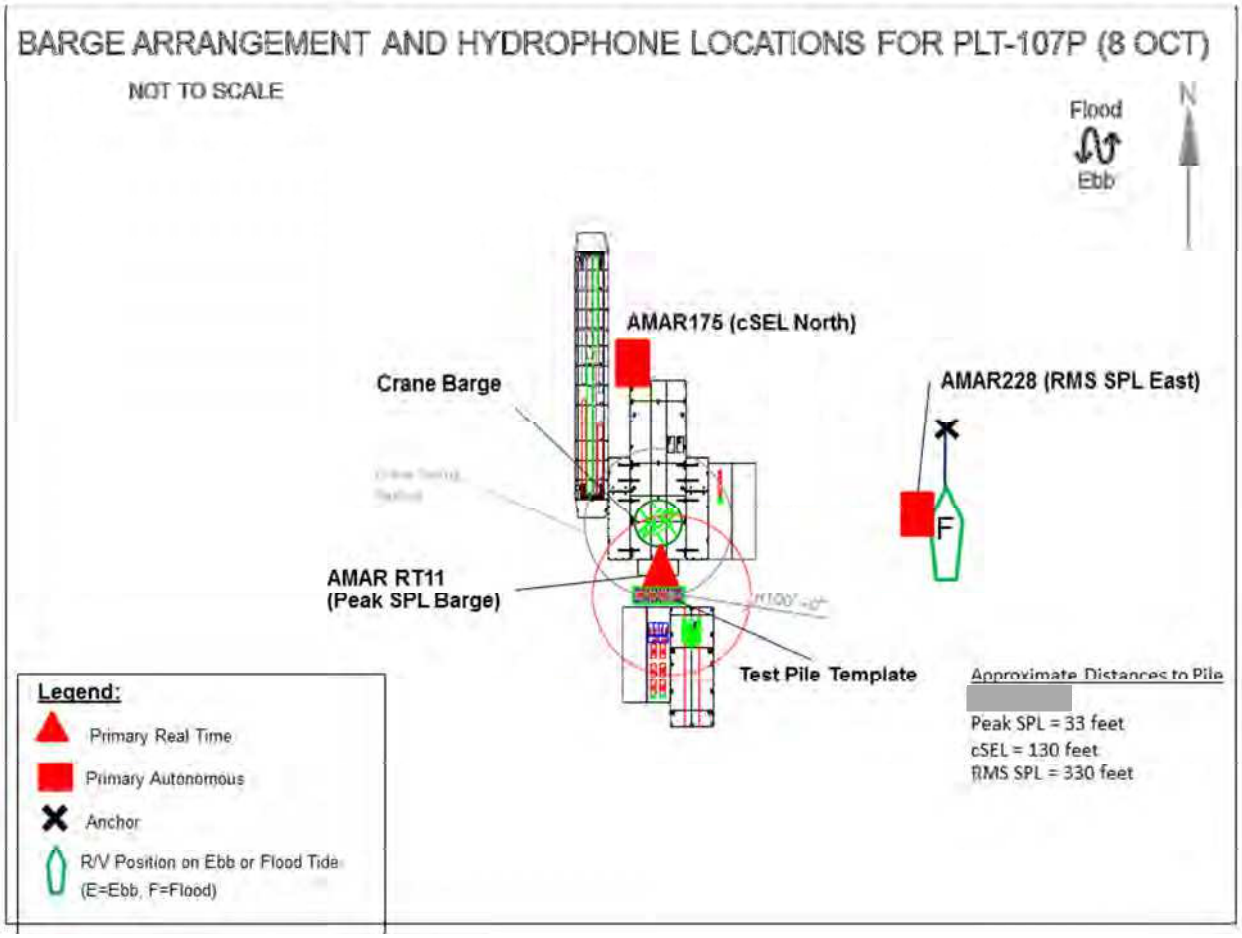

Figure 1. Plan view of pile and barge layout, 08 October 2013, Test Pile PLT-107P.

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	32	13	194	198
cSEL North (up current)	AMAR-175	139	13	180	178
rms SPL East (cross current)	AMAR-228	658	12	153	159

* 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 14 ft, and did not exceed NMFS criteria of a diameter of 40 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 146 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 146 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	14
187 dB re 1 µPa^2·s cSEL*	146
150 dB re 1 µPa rms SPL (1 s integration time)	374

* At the end of pile driving

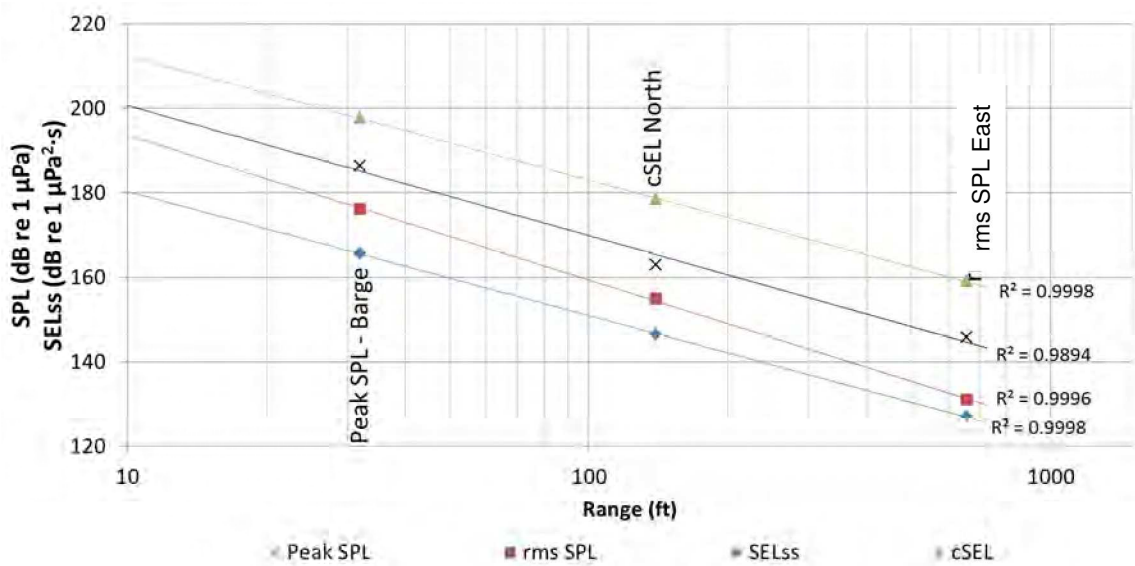

Figure 2. Regression based on mean values of the SELss, peak SPL, cSEL, and rms SPL from each recorder from pile driving of Test Pile PLT-107P, 08 October 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents the total sound energy measured during the pile driving.

1.3. Observations

The hammer energy was nearly constant at 180 ± 10 kip-ft (Figure 3, Figure 4) throughout the pile driving at PLT-107P. The average current was almost slack (0.2 knots, Figure 3, Figure 5) during the pile driving. The NAS air pressure and air flow were constant at 65 psi and 1750–1800 cfm throughout the pile driving (Figure 6). However, there was no observable effect on the measured sound levels from the change in current at location Peak SPL Barge. There was an increase of approximately 10 dB at locations cSEL North and rms SPL East as the current slowed. This increase occurred while hammer energy and air pressure remained constant over those periods. As such, there appears to be no correlation with river currents, hammer energy, or NAS settings.

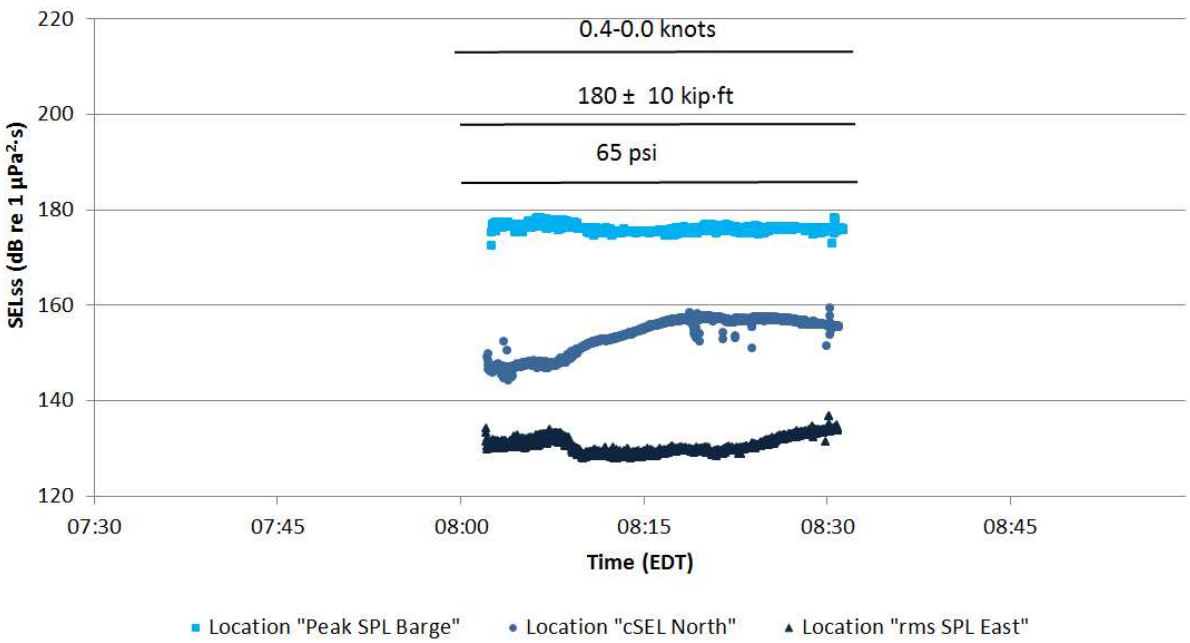

Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 08 October 2013.

Table 4. JASCO and construction activities for 08 October 2013.

Time (EDT)	Activity
05:55	Arrive at dock, prep recorders

06:30	Leave dock for job site
06:40	Arrive at 4100 barge; begin deployment
07:20	Begin lifting hammer; deployment complete
08:03	Start pile driving on PLT-107
08:32	Complete pile driving on PLT-107; recover AMAR-228 and standby for PLT-107
12:34	Deploy AMAR-228 for PLT-107
14:37	Start lifting hammer for PLT-107
14:57	Start pile driving on PLT-107
15:42	Stop pile driving on PLT-107; begin recovery
16:10	Recovery complete, en route to dock
18:30	All work completed

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Two-tier unconfined bubble curtain

NAS settings: 1750–1800 cfm, 65 psi

2.2.2. Impact Hammering Log

Total energy: 290,389 kip-ft (394 MJ)

Total number of strikes:

Maximum per-strike energy: 188.6 kip-ft (255 kJ)

Net pile driving duration (hh:mm:ss): 00:03:56

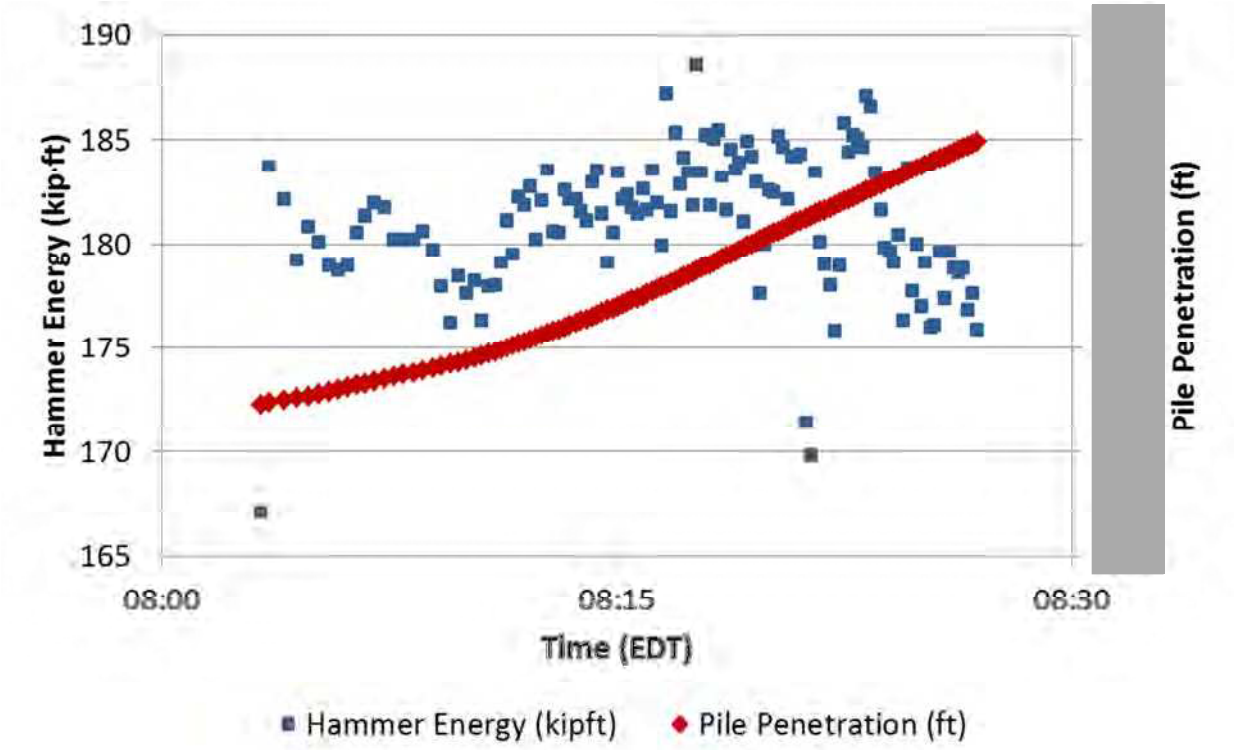

Figure 4. Hammer energy and pile penetration for installation of PLT-107P, 08 October 2013.

3. Weather and River Conditions

Table 5 provides the predicted currents at the project site on 08 October 2013. No sound speed measurements were made on 08 October due to an equipment failure. Figure 5 provides the currents measured with the Active Doppler Current Profiler (ADCP) at the project site on 08 October.

Table 5. Weather conditions, current, and predicted local tide times (EDT).

Weather conditions:	Sunny, light winds
Full ebb current:	06:15 (–2.2 knots)
Slack current:	09:16*
Full flood current:	11:40 (0.8 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=

* Note that actual measurements (Figure 5) shows slack tide occurring around 08:30.

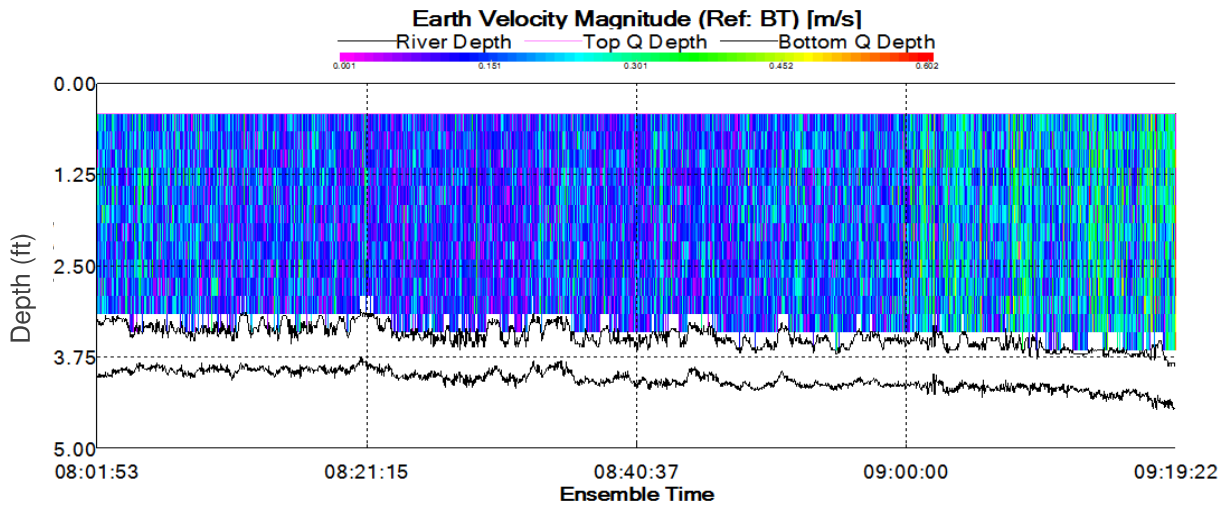

Figure 5. ADCP current measurements from 08 October 2013 from the Alpine vessel, located 658ft East of PLT107P at rms SPL East (41.0711 N, 73.9029 W)

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 6 provides information on the real-time monitoring equipment used on 08 October 2013. Table 7 provides location information on the real-time recorders.

Table 6. Real-time monitoring equipment for Test Pile PLT-107P, 08 October 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:	–211.1 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 7. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 08 October 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	73.90521	07:30	13	32

4.2. Autonomous Monitoring Equipment

Table 8 provides information about the autonomous monitoring equipment used on 08 October 2013.

Table 9 provides the locations of the autonomous recorders.

Table 8. Autonomous monitoring equipment for Test Pile PLT-107P, 08 October 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-228 sensitivity:	–199.74 dB re 1 V/µPa	1
AMAR-175 sensitivity:	–200.94 dB re 1 V/µPa	1

Table 9. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 08 October 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
cSEL North (up current)	AMAR-175	41.07158	–73.9053	07:10	13	139
rms SPL East (cross current)	AMAR-228	41.0711	-73.9029	08:05	12	658

Appendix A. Pile Driving Plots

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

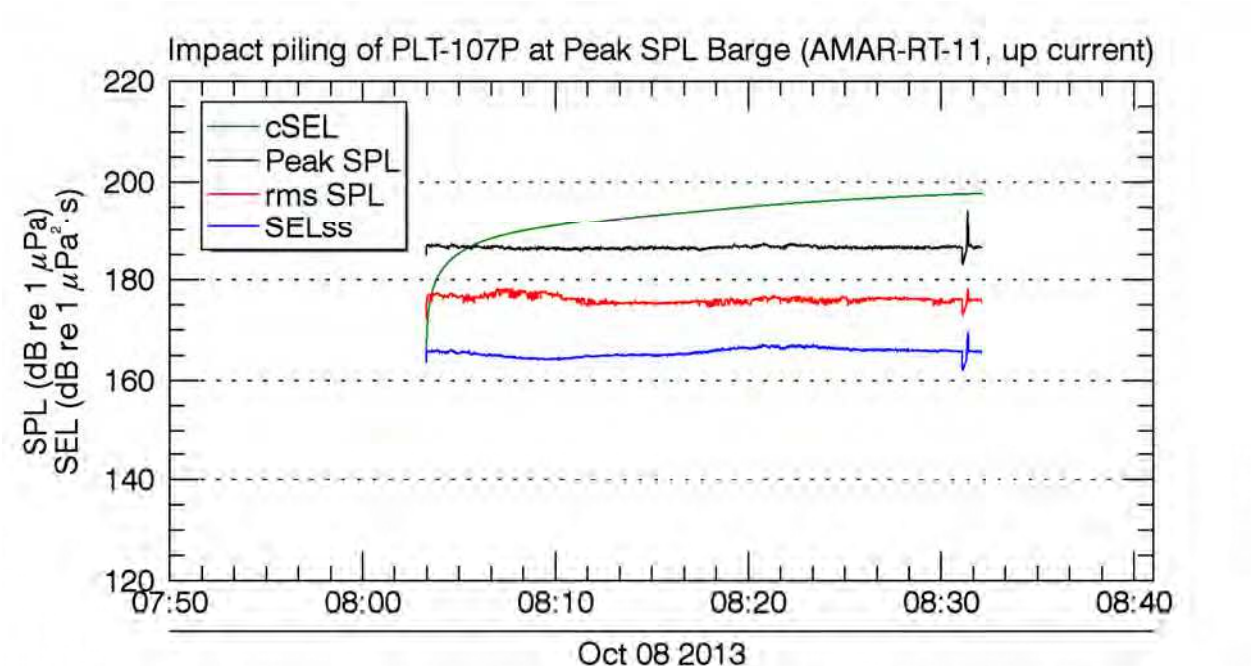

Figure 6. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-107P measured 32 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

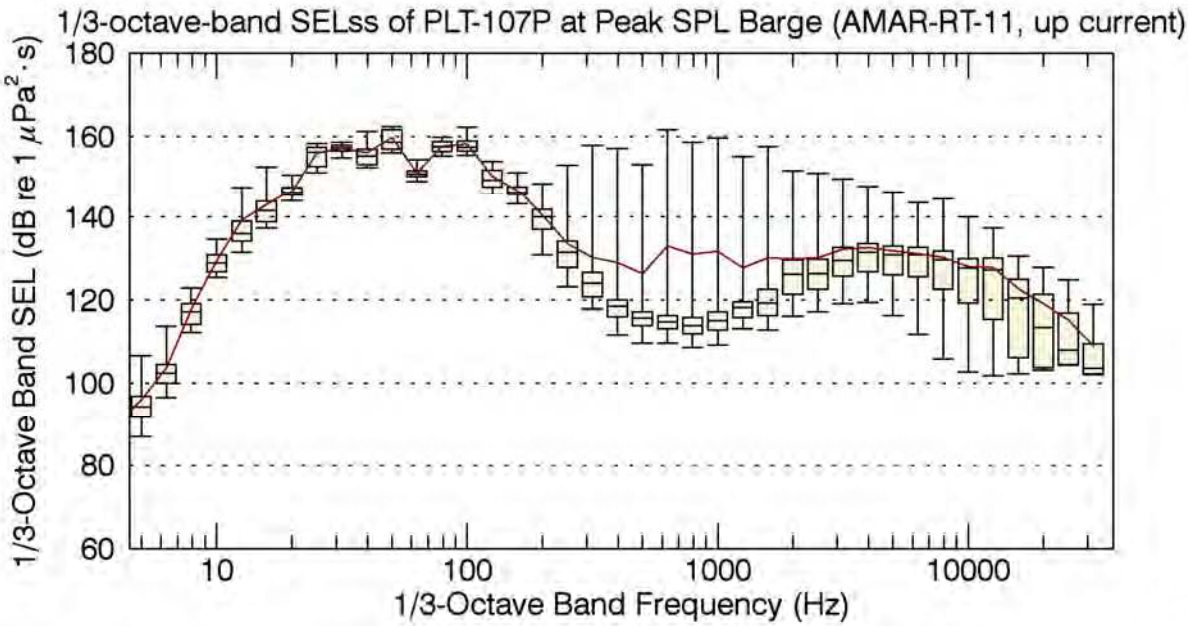

Figure 7. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-107P measured 32 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 10. Sound levels for the pile driving of Test Pile PLT-107P measured 32 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 µPa²·s)
L_{max}	194.4	178.3	169.6
L_5	186.8	177.5	166.8
L_{25}	186.5	176.4	166.2
L_{50}	186.4	176.1	165.7
L_{75}	186.2	175.4	165.0
L_{95}	186.0	175.1	164.4
L_{mean}	186.4	176.1	165.7

* 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 cSEL North

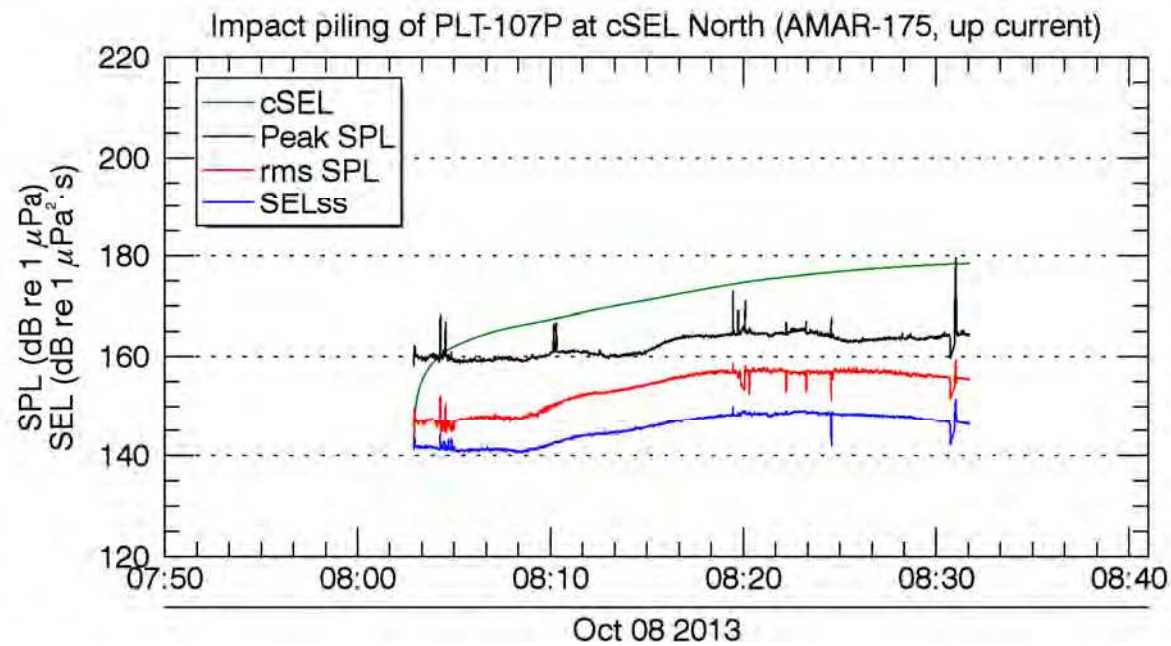

Figure 8. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-107P measured 139 ft from the pile at location cSEL North using AMAR-175. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

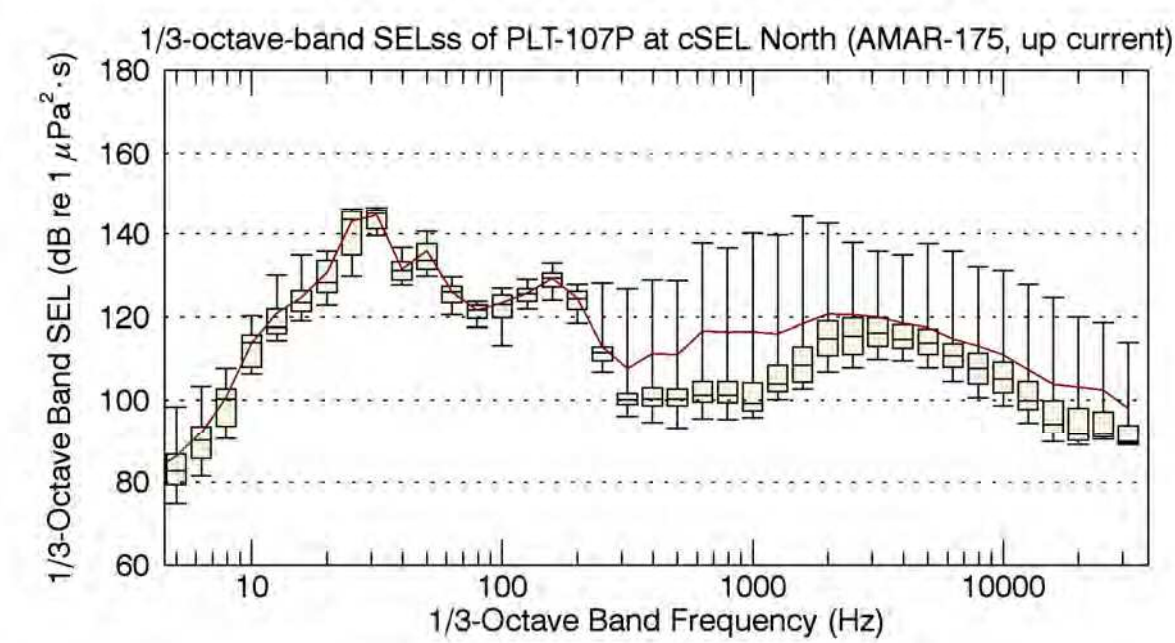

Figure 9. Distribution of 1/3-octave SELss for the pile driving of Test Pile PLT-107P measured 139 ft from the pile at location cSEL North using AMAR-175. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 11. Sound levels for the pile driving of Test Pile PLT-107P measured 139 ft from the 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 µPa^2·s)
L_{max}	179.7	159.5	151.5
L_5	165.0	157.3	148.8
L_{25}	164.1	156.8	148.2
L_{50}	163.2	155.6	146.7
L_{75}	160.2	150.2	142.5
L_{95}	159.2	147.0	140.9
L_{mean}	163.0	154.9	146.4

* 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.3. Impact Pile-Driving Sound Levels rms SPL East

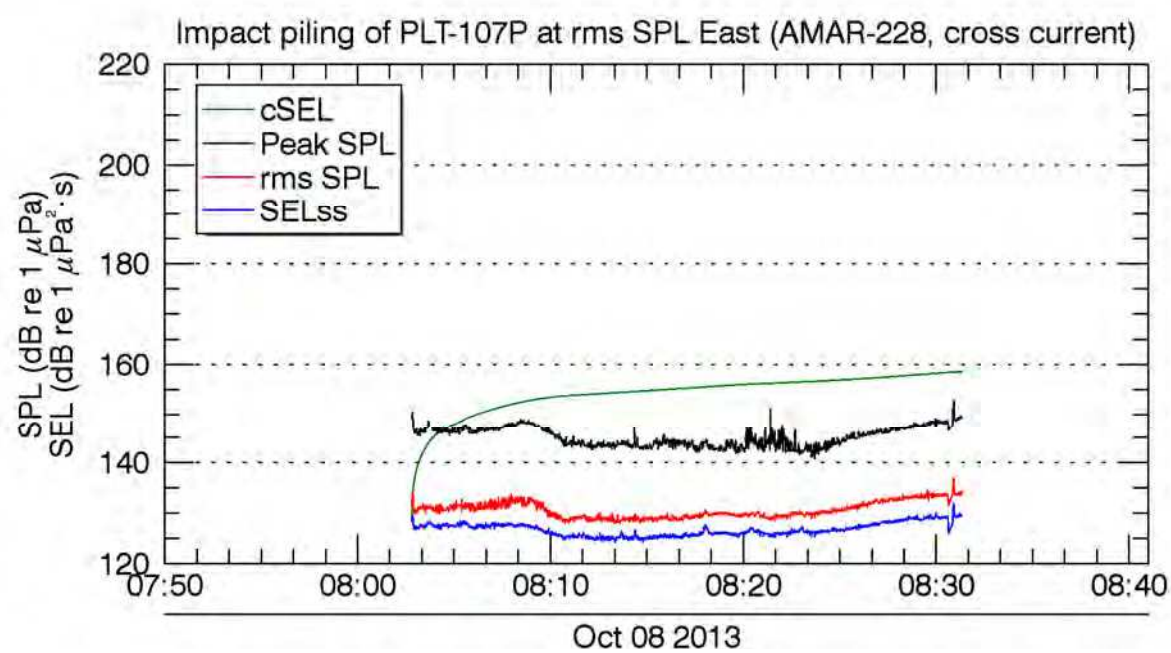

Figure 10. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-107P measured 658 ft from the pile at location rms SPL East using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

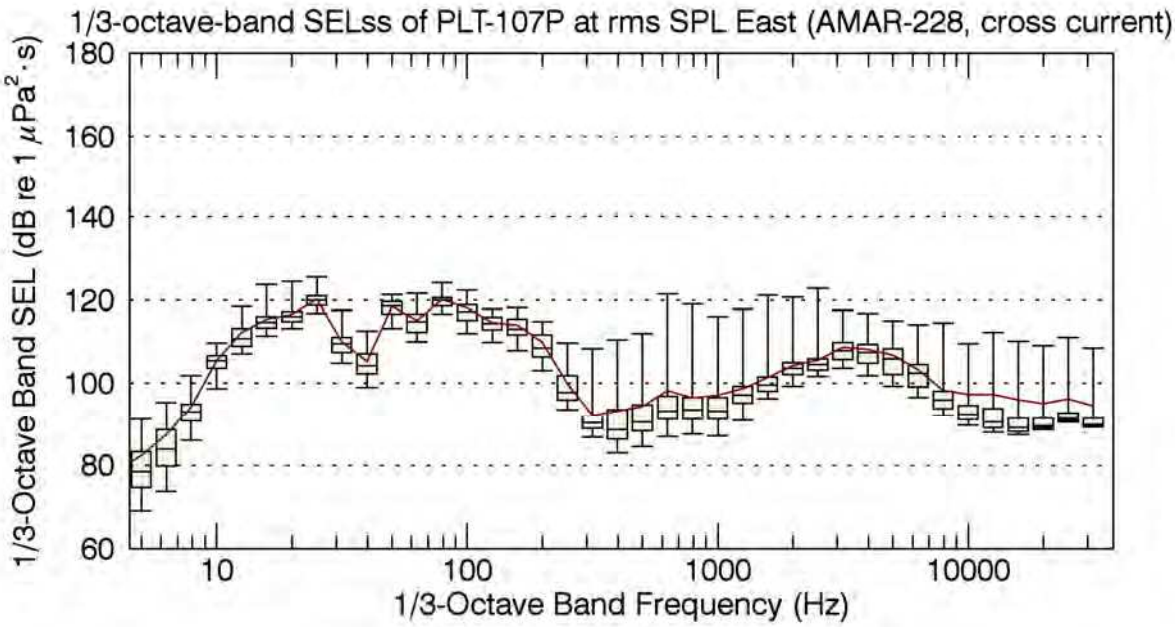

Figure 11. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-107P measured 658 ft from the pile at location rms SPL East using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 12. Sound levels octave for the pile driving of Test Pile PLT-107P measured 658 ft from the pile at location rms SPL East 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}	153.0	136.9	132.1
L_5	148.5	133.5	129.1
L_{25}	146.9	131.9	127.7
L_{50}	145.4	130.4	126.7
L_{75}	143.5	129.4	125.7
L_{95}	142.5	128.6	125.0
L_{mean}	145.8	131.0	127.0

* 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}).

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 107 Installation

Daily Memorandum for 8 October 2013

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7 March 2014

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1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-107 is a [redacted] pile driven at the construction site of the New NY Bridge on the West side of the navigation channel on 08 October 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 34–498 ft from the pile (Figure 1 and Table 2). Pile driving occurred between 14:57–15:42 Eastern Daylight Time (EDT). Full flood current occurred at 11:40 and slack current occurred at 15:23 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-107 activities, 08 October 2013.

Date:	08 October 2013
Pile-Driving Activity	
Test pile identifier:	PLT-107
Pile diameter:	[redacted]
Water depth:	13 ft
Hammer type:	Impact (IHC S-280)
Total hammer strikes:	[redacted]
Total penetration:	[redacted]
Net duration of pile driving (hh:mm:ss):	~00:27:00*
Maximum single strike energy:	189.6 thousand foot-pounds (kip-ft), (257 kJ)
Total energy transferred:	271898 kip-ft , (369 MJ)
Noise Attenuation System (NAS)	
Two-tier unconfined bubble curtain airflow rate:	1750–1800 cubic feet per minute (cfm), 65 pounds per square inch (psi)
River conditions during pile driving:	Flood tide to slack current, 0.8-0.0 knots current (0.4–0.0 meters per second [m/s], depth dependent; Table 5 and Figure 5)

*The IHC hammer log file appeared to be corrupted. Approximate pile drive given based on number of 1503 strikes at an average of 57 strikes per minute.

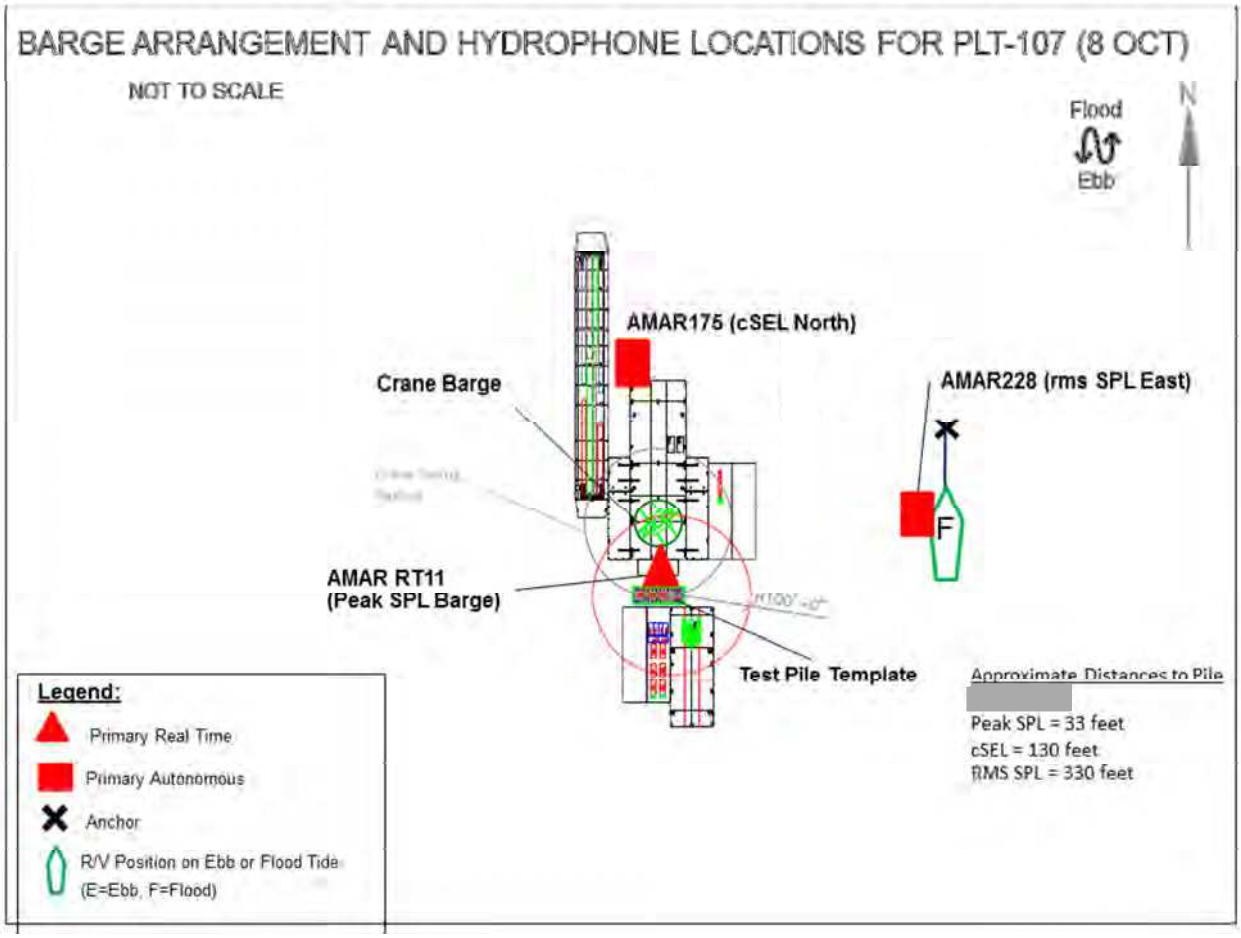


Figure 1. Plan view of pile and barge layout, 08 October 2013, Test Pile PLT-107.

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	34	13	186	197
cSEL North (down current)	AMAR-175	148	13	168	179
rms SPL East (cross current)	AMAR-228	498	12	162	164

* 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 8 ft, and did not exceed NMFS criteria of a diameter of 40 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 156 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 156 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	8
187 dB re 1 µPa^2·s cSEL*	156
150 dB re 1 µPa rms SPL (1 s integration time)	468

*At the end of pile driving

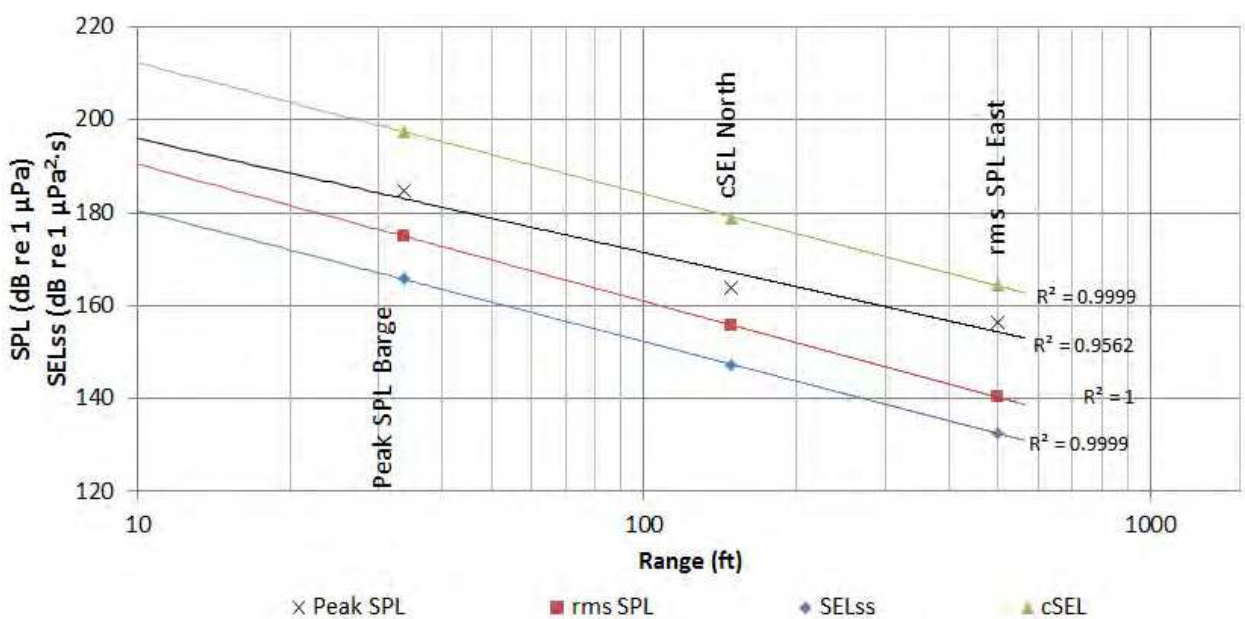


Figure 2. Regression based on mean values of the SELss, peak SPL, cSEL, and rms SPL from each recorder from pile driving of Test Pile PLT-107, 08 October 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents the total sound energy measured during the pile driving.

1.3. Observations

The hammer energy during pile driving at PLT-107 was nearly constant at 180 ± 10 kip-ft (Figure 3, Figure 4). Similarly the NAS air pressure and airflow were constant at 65 psi and 1750–1800 cfm (Figure 3). Pile driving occurred at the flood current into the slack current. Currents were variable throughout pile driving with a minimum current of 0 knots to a maximum of 0.8 knots (Figure 3, Figure 5).The measured sound levels showed different characteristics at each location (Figure 3, Figure 6, Figure 8, and Figure 10). Recorded SELss at location Peak SPL Barge remained constant as the pile was driven. However the SELss recorded at locations cSEL North and rms SPL East increased by approximately 15 dB from the start to the end of pile driving. The reason for this increase is unknown as the same trend was not observed at the other hydrophone deployed up-current (Peak SPL Barge). Changes in sound level did not appear to correlate with the river currents, hammer energy or NAS system settings.

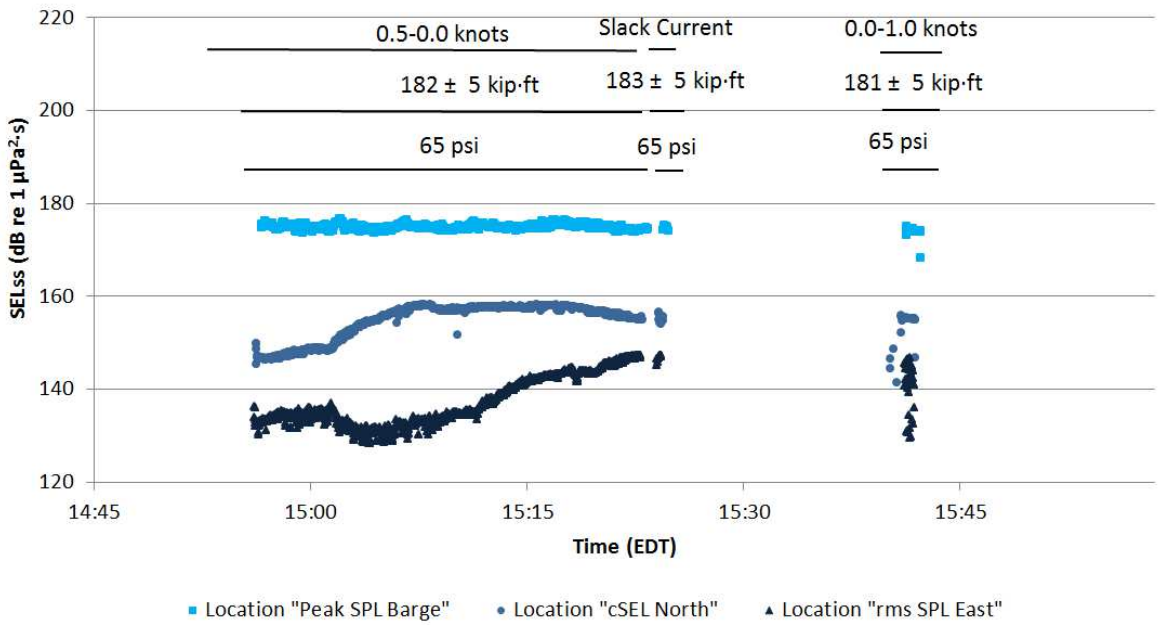


Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 08 October 2013.

Table 4. JASCO and construction activities for 08 October 2013.

Time (EDT)	Activity
05:55	Arrive at dock, prep recorders
06:30	Leave dock for job site
06:40	Arrive at 4100 barge; begin deployment
07:20	Begin lifting hammer; deployment complete
08:03	Start pile driving on PLT-107P
08:32	Complete pile driving on PLT-107P; retrieve AMAR-228 and standby for PLT-107
12:35	Deploy AMAR-228 for PLT-107
14:37	Start lifting hammer for PLT-107
14:57	Start pile driving on PLT-107
15:42	Stop pile driving on PLT-107; begin recovery
16:10	Recovery complete, en route to dock
18:30	All work completed

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Two-tier unconfined bubble curtain

NAS settings: 1750–1800 cfm, 65 psi

2.2.2. Impact Hammering Log

Total energy: 271,898 kip-ft (369 MJ)

Total number of strikes:

Maximum per-strike energy: 189.6 kip-ft (257 kJ)

Net pile driving duration (hh:mm:ss): ~00:27:00 *Approximated from number of strikes

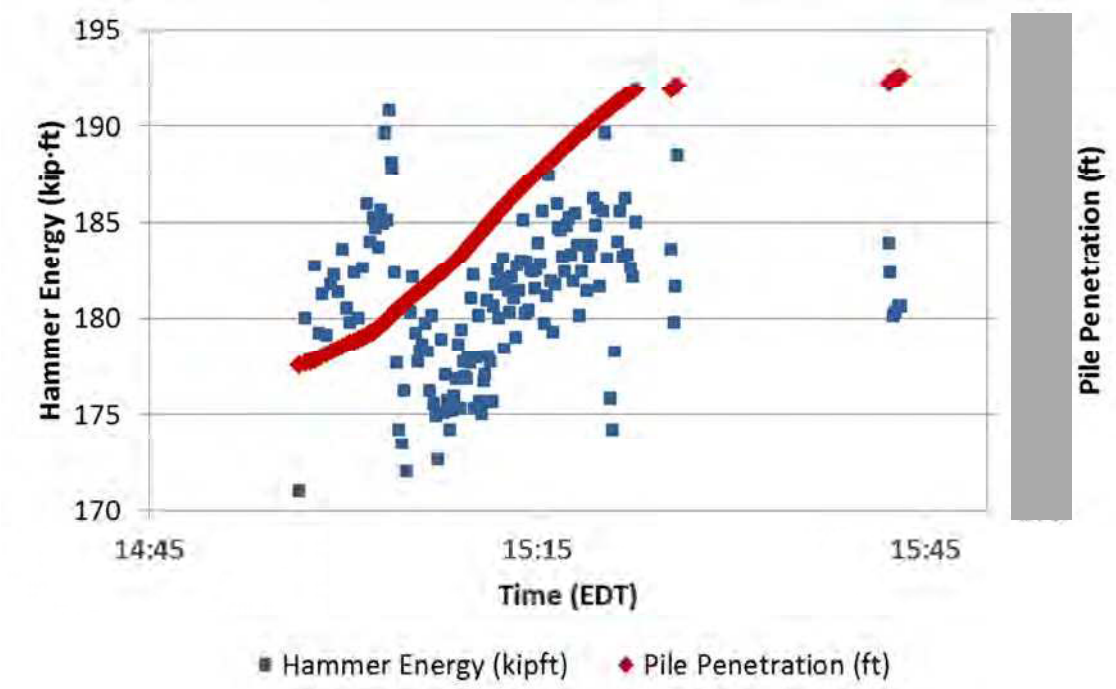


Figure 4. Hammer energy and pile penetration for installation of PLT-107, 08 October 2013.

3. Weather and River Conditions

Table 5 provides the predicted currents at the project site on 08 October 2013. No sound speed measurements were made on 08 October due to an equipment failure. Figure 5 provides the measured currents using an Acoustic Doppler Current Profiler (ADCP) at the project site on 08 October.

Table 5. Weather conditions and predicted local current times (EDT).

Weather conditions:	Sunny, light winds
Full ebb current:	18:55 (-2.6 knots)
Slack current:	15:23
Full flood current:	11:40 (1.6 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. Tide data from 08 October 2013 recorded from the Alpine vessel at location rms SPL East (41.0707 N, 73.9034 W).

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 6 provides information on the real-time monitoring equipment used on 08 October 2013.

Table 7 provides location information on the real-time recorders.

Table 6. Real-time monitoring equipment for Test Pile PLT-107, 08 October 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:	–211.1 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 7. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 08 October 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	41.07126	73.90521	07:30	13	33

4.2. Autonomous Monitoring Equipment

Table 8 provides information about the autonomous monitoring equipment used on 08 October 2013.

Table 9 provides the locations of the autonomous recorders.

Table 8. Autonomous monitoring equipment for Test Pile PLT-107, 08 October 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-228 sensitivity:	–199.74 dB re 1 V/µPa	1
AMAR-175 sensitivity:	–200.94 dB re 1 V/µPa	1

Table 9. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 08 October 2013

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
cSEL North (down current)	AMAR-175	41.07158	–73.9053	07:10	13	148
rms SPL East (cross current)	AMAR-228	41.0707	–73.9034	12:35	12	498

Appendix A. Pile Driving Plots

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

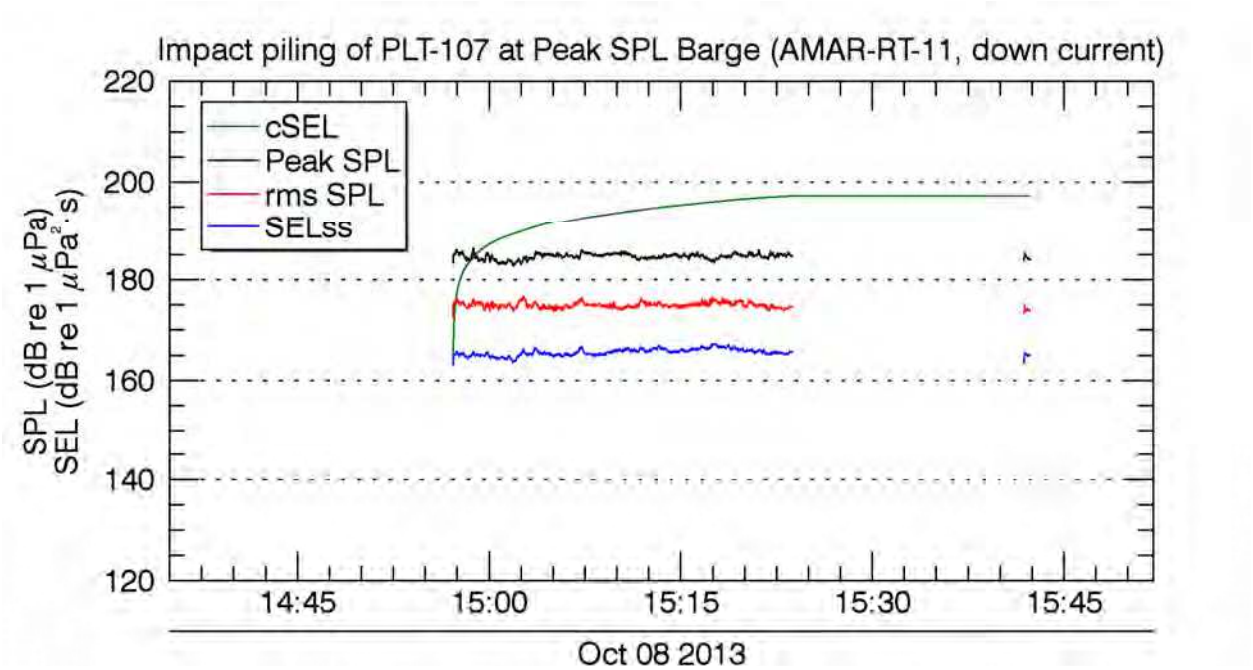


Figure 6. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-107 measured 34 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

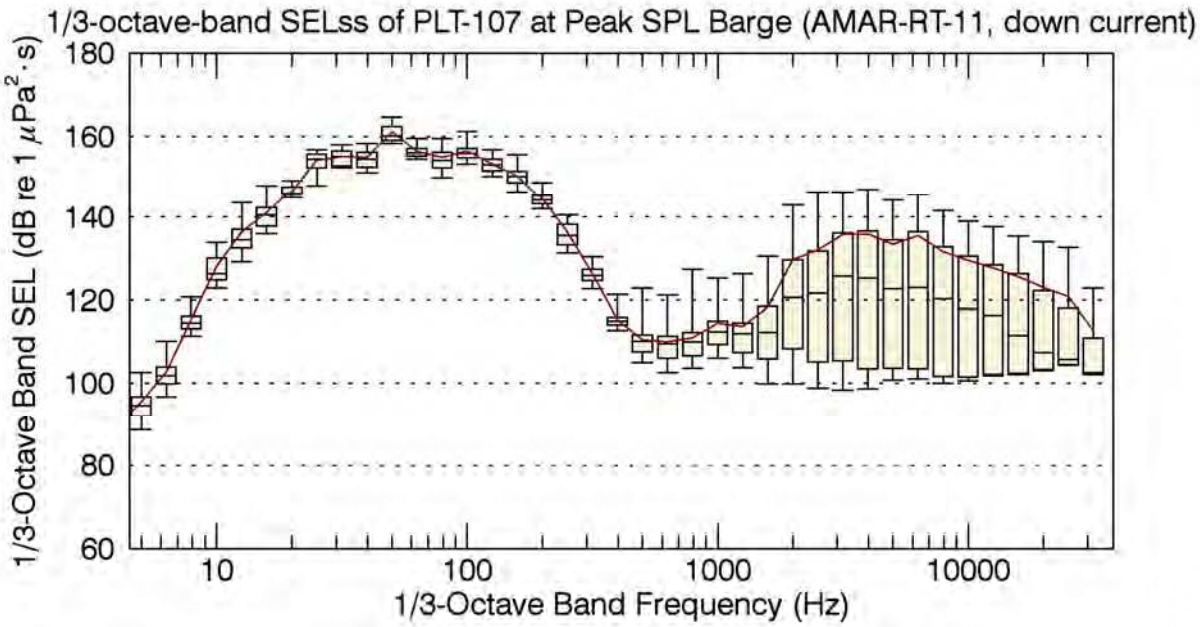


Figure 7. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-107 measured 34 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 10. Sound levels for the pile driving of Test Pile PLT-107 measured 34 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 µPa²·s)
L_{max}	186.4	176.6	167.3
L_5	185.4	175.8	166.7
L_{25}	185.0	175.2	166.1
L_{50}	184.7	174.8	165.6
L_{75}	184.3	174.5	165.2
L_{95}	183.5	174.0	164.5
L_{mean}	184.6	174.9	165.7

* 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 cSEL North

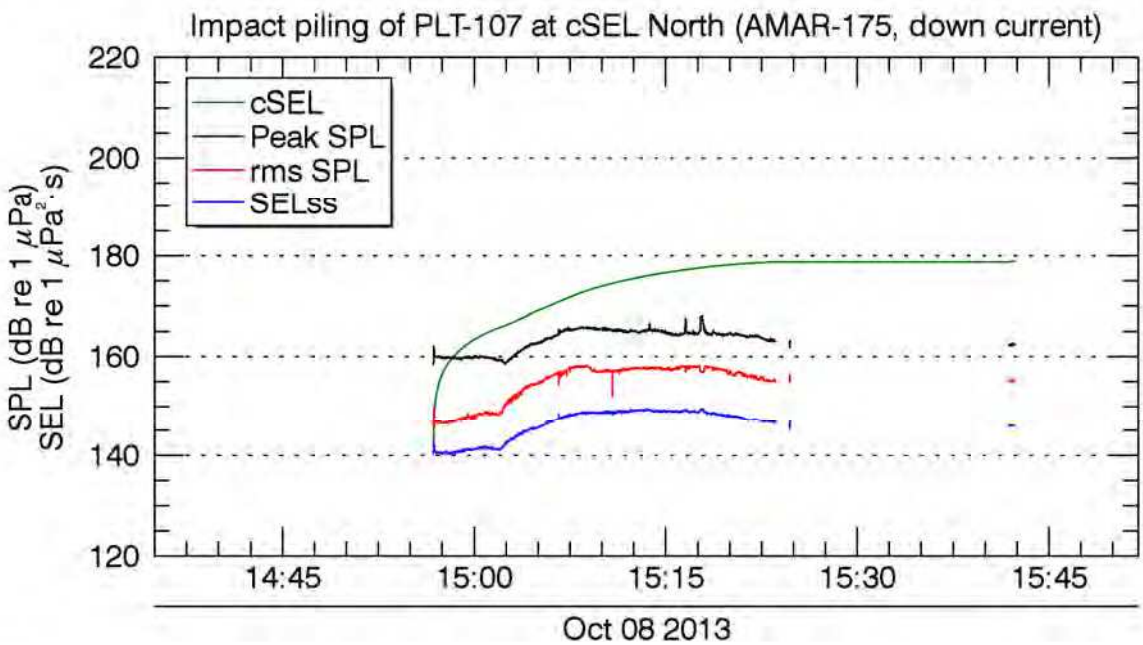


Figure 8. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-107 measured 148 ft from the pile at location cSEL North using AMAR-175. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

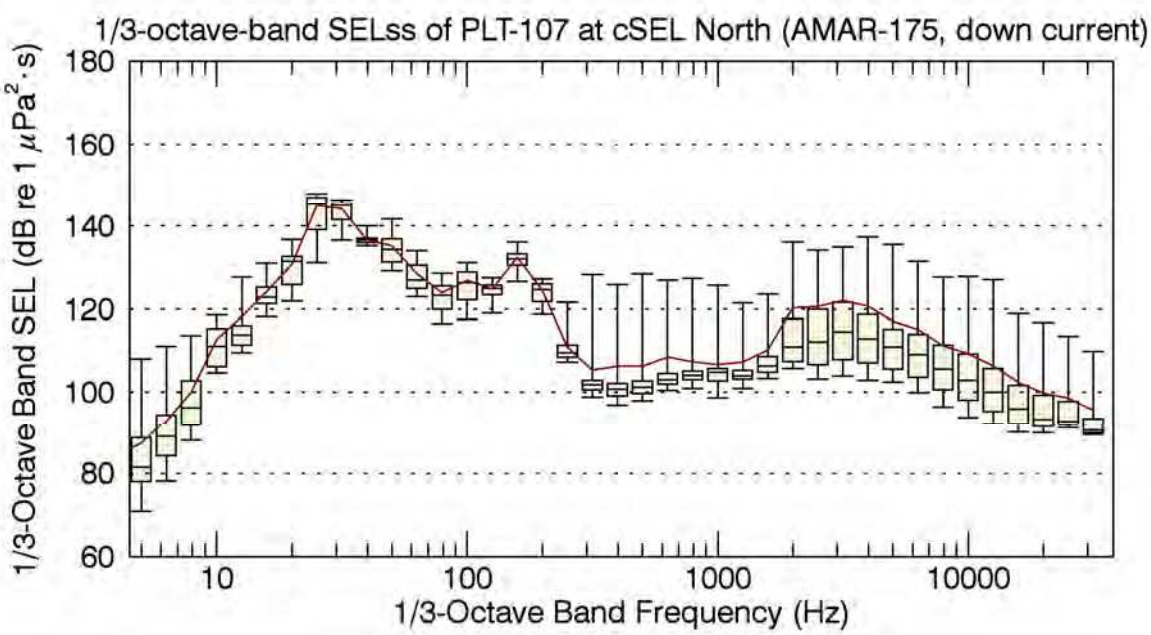


Figure 9. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-107 measured 148 ft from the pile at location cSEL North using AMAR-175. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 11. Sound levels for the pile driving of Test Pile PLT-107 measured 148 ft from the 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 µPa^2·s)
L_{max}	168.3	158.3	149.6
L_5	165.7	158.0	149.2
L_{25}	165.1	157.6	148.9
L_{50}	164.3	156.5	147.8
L_{75}	160.7	152.2	143.8
L_{95}	159.5	146.8	140.6
L_{mean}	163.7	155.8	147.2

* 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 East

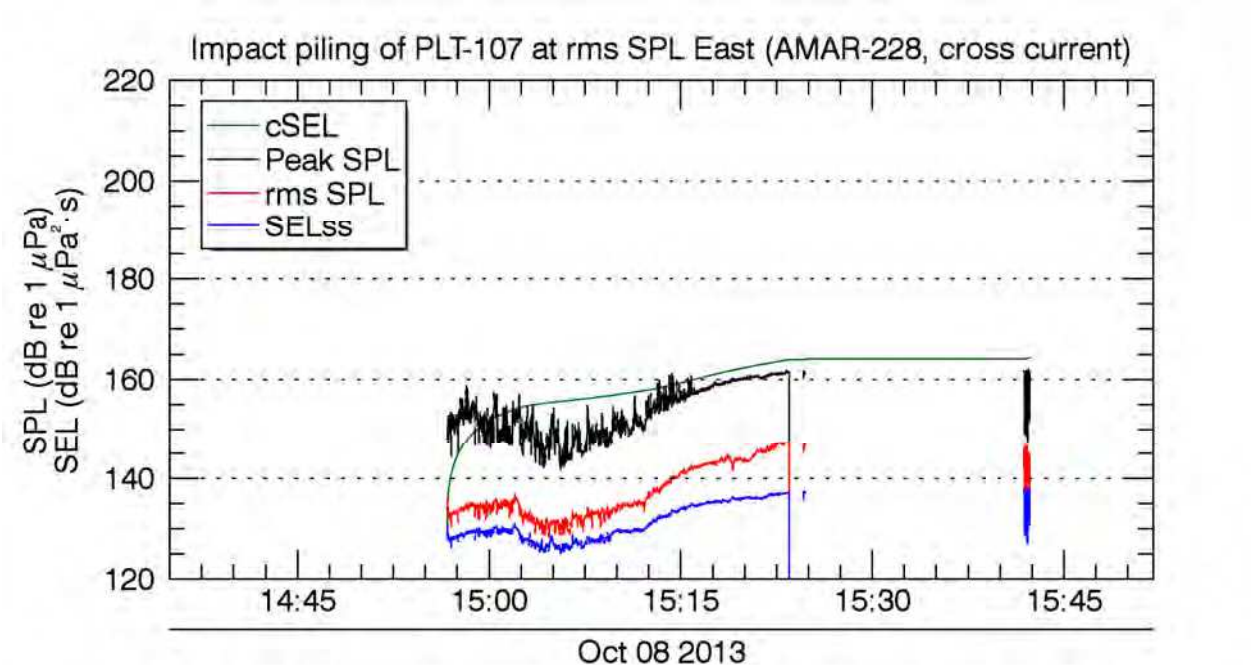


Figure 10. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-107 measured 498 ft from the pile at location rms SPL East using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

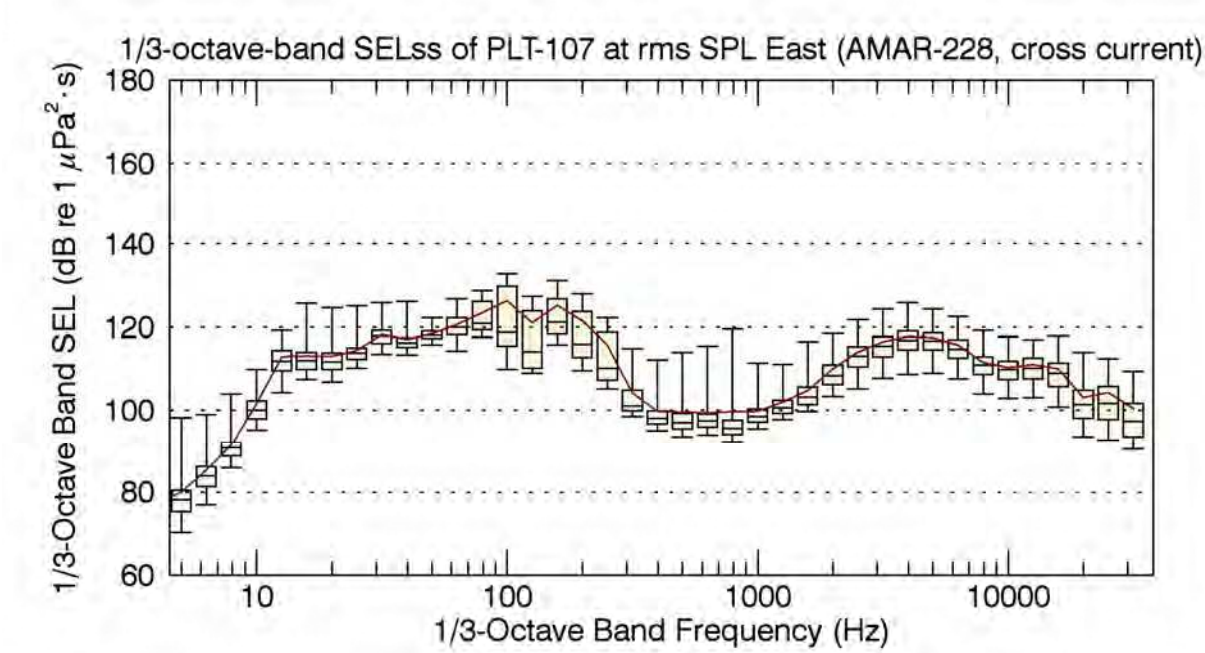


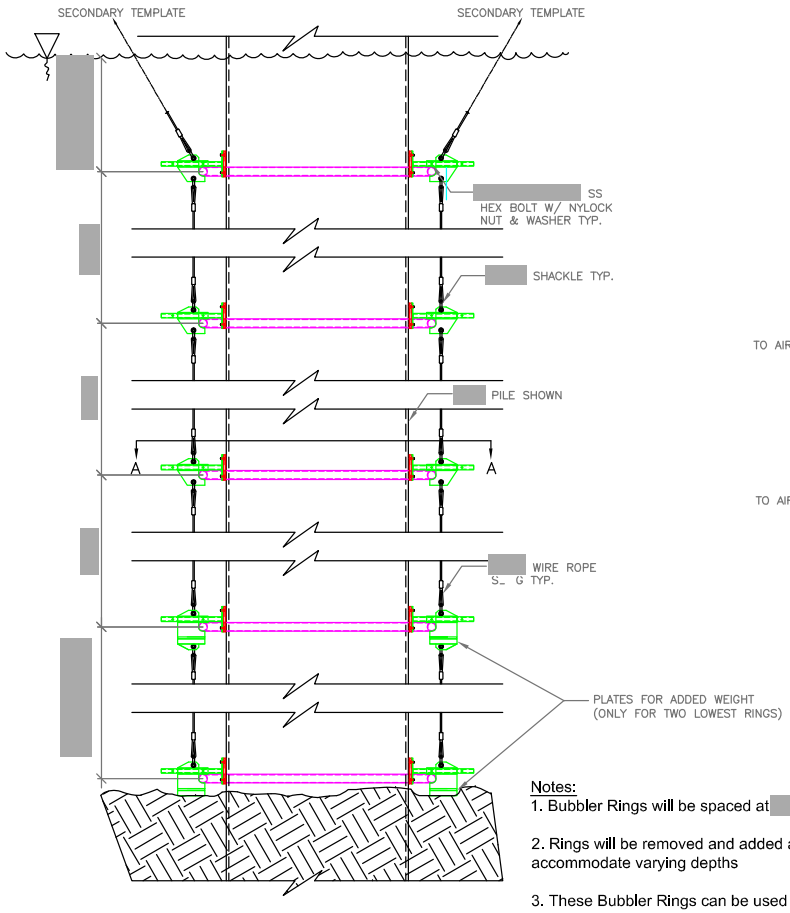
Figure 11. Distribution of1/3-octave-band SELss for the pile driving of Test Pile PLT-107 measured 498 ft from the pile at location rms SPL East using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 12. Sound levels octave for the pile driving of Test Pile PLT-107 measured 498 ft from the pile at location rms SPL East using AMAR-228.

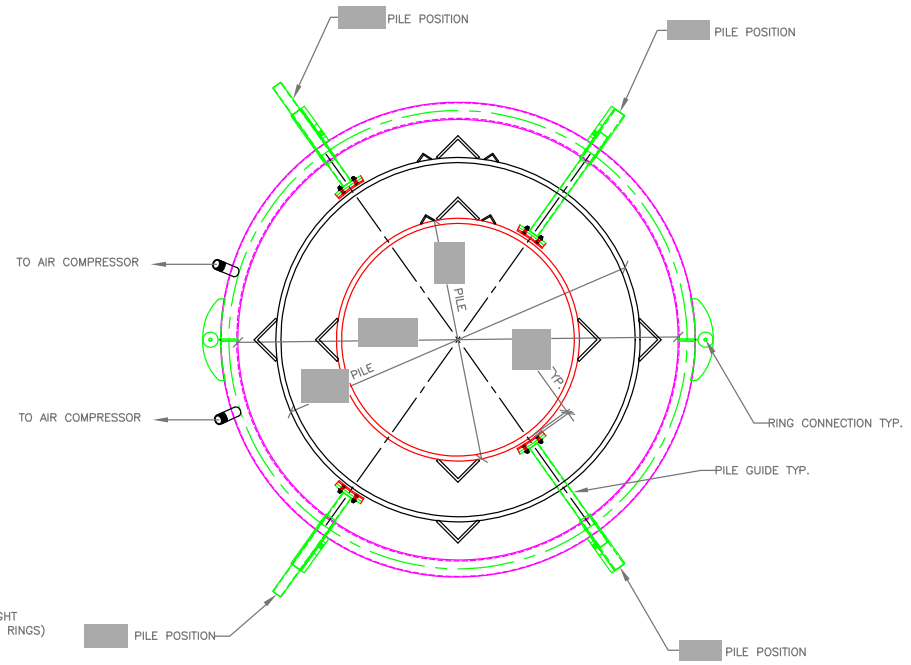
Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SELss (dB re 1 µPa²·s)
L_{max}	161.9	147.4	138.0
L_5	161.2	146.1	136.9
L_{25}	158.6	142.6	135.1
L_{50}	152.9	135.0	129.7
L_{75}	149.2	133.1	128.2
L_{95}	145.2	130.7	126.4
L_{mean}	156.3	140.3	132.6

* 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}).

Attachment 2 – Design Plans for the Multi-Tier Bubble Curtain (Drawings 1UBCR through 6UBCR)



ELEVATION - BUBBLER RINGS PILE
SCALE: NTS



A 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

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

NEW YORK STATE THRUWAY AUTHORITY

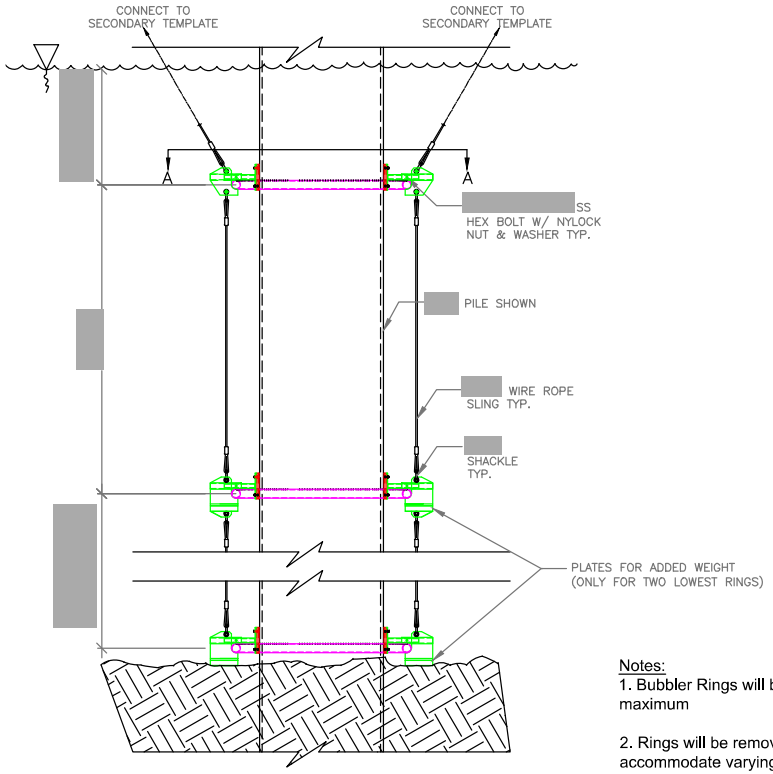
TAPPAN ZEE CONSTRUCTORS, LLC

TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS

CONTRACT NUMBER: –
DATE: 5/20/13
DRAWING NUMBER: 1UBCR

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

DOCUMENT TRACKING CODE: –

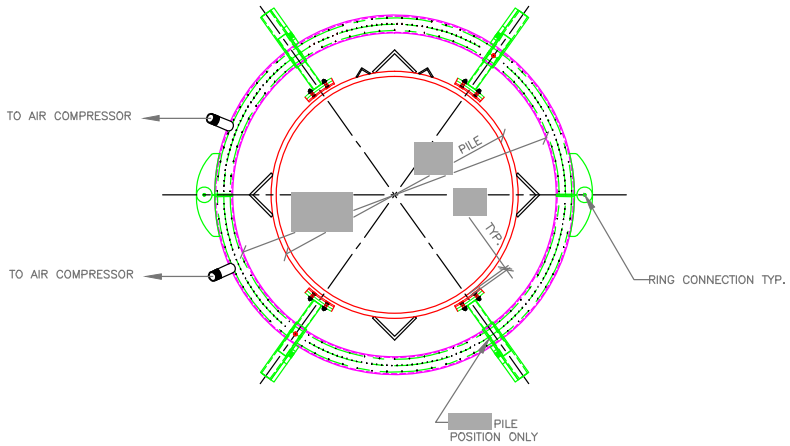


ELEVATION - BUBBLER RINGS PILES
SCALE: NTS

Notes:
1. Bubbler Rings will be spaced at 10'-0" centers maximum

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

3. These Bubbler Rings can be used on piles only



A - PLAN - BUBBLER RINGS
SCALE: NTS

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

NEW YORK STATE THRUWAY AUTHORITY

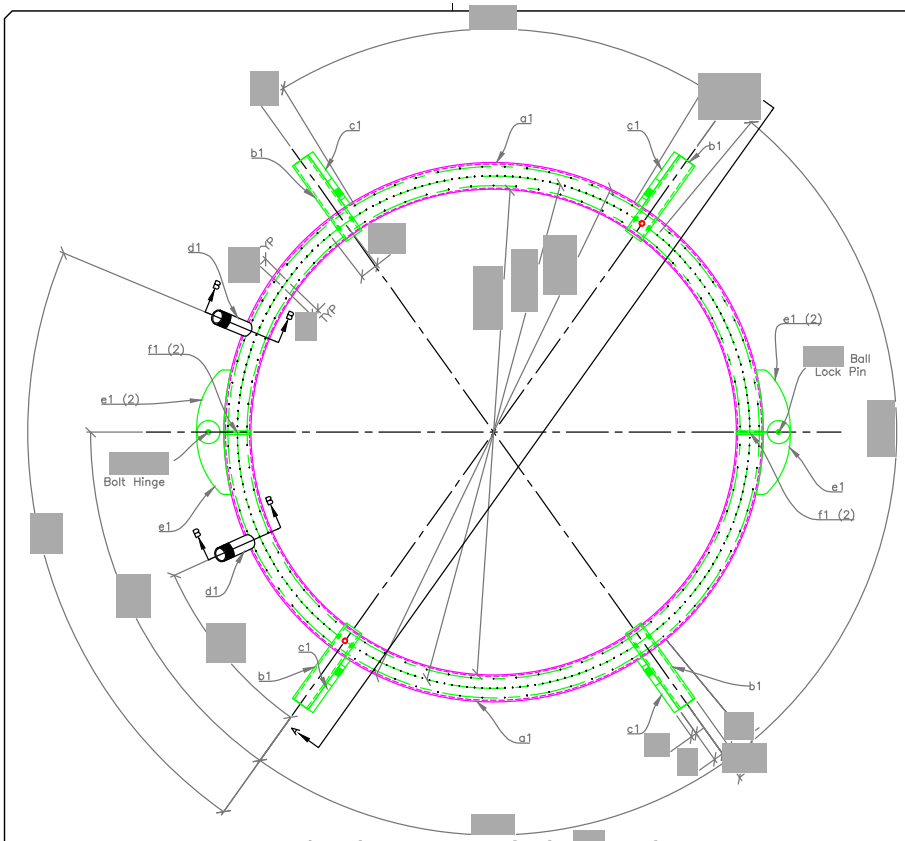
TAPPAN ZEE CONSTRUCTORS, LLC

TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS

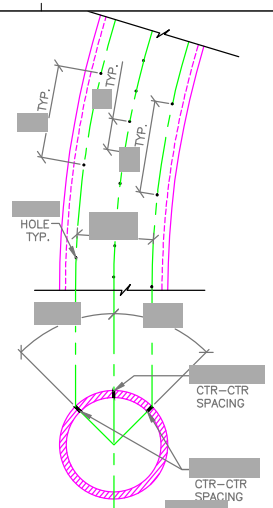
CONTRACT NUMBER: –
DATE: 5/19/13
DRAWING NUMBER: 2UBCR

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

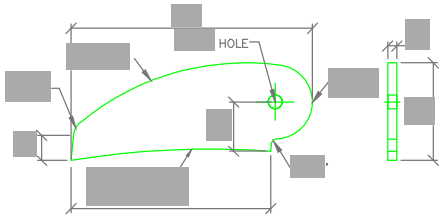
DOCUMENT TRACKING CODE: -



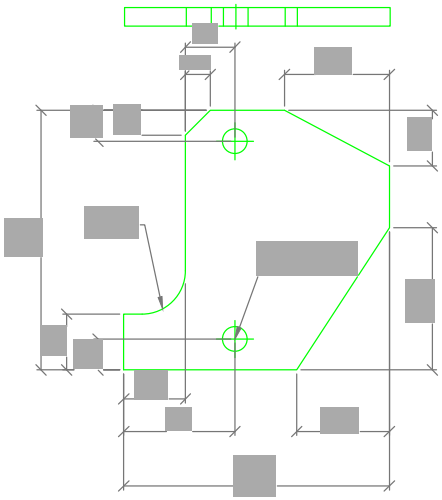
MK 1T - TOP BUBBLER RING FOR PILES
SCALE: NTS



TYPICAL SECTION HOLE LAYOUT
SCALE: NTS



e1-PLATE T6061 ALUMINUM
SCALE: NTS



c1-PLATE T6061 ALUMINUM
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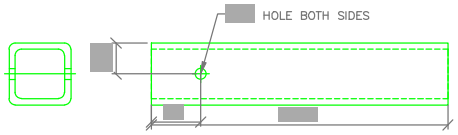

b1-TS T6061 ALUMINUM
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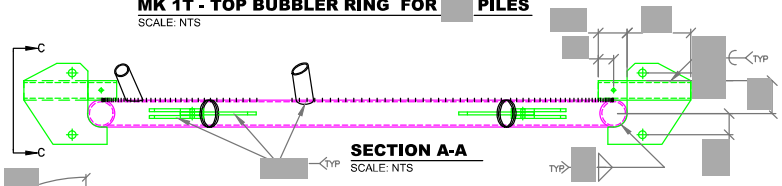
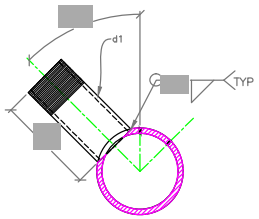
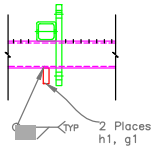


SECTION A-A
SCALE: NTS



SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS



SECTION C-C
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
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS

CONTRACT NUMBER: –
DATE: 5/19/13
DRAWING NUMBER: 3UBCR

DOCUMENT TRACKING CODE: -

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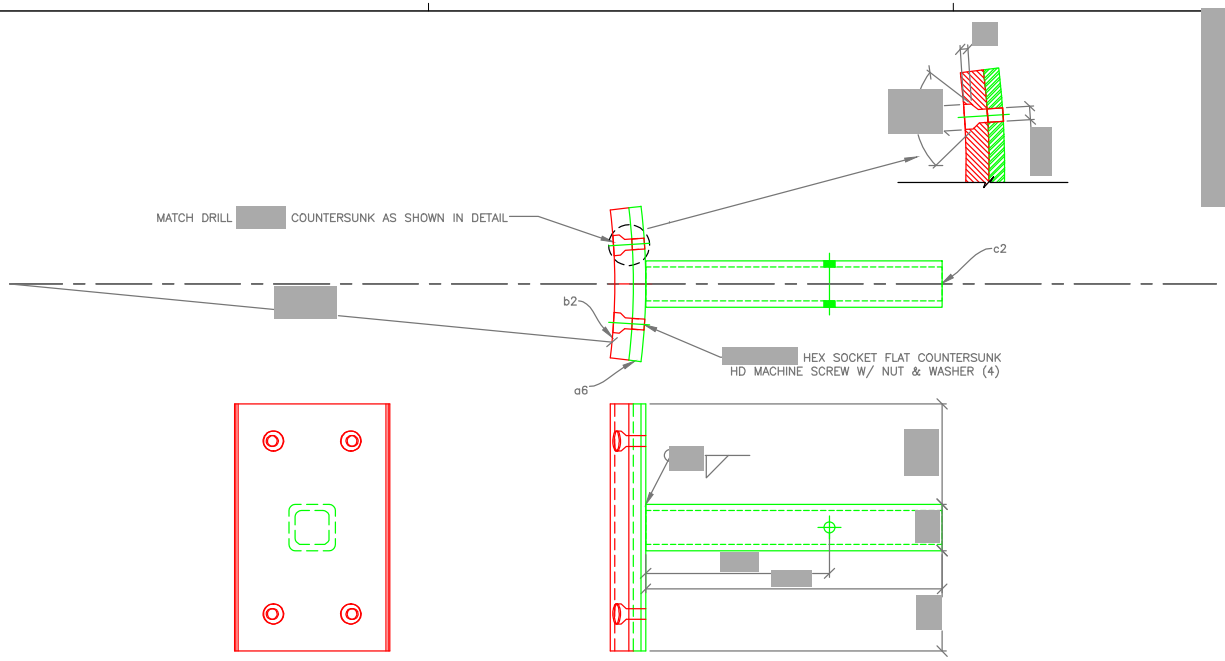
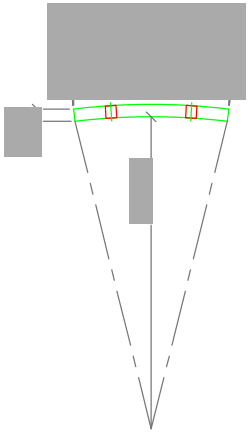
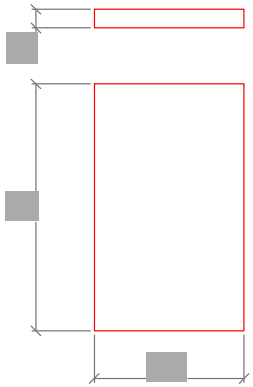
CHECKED BY: –
DESIGNED BY: –
DESIGN SUPERVISOR: –

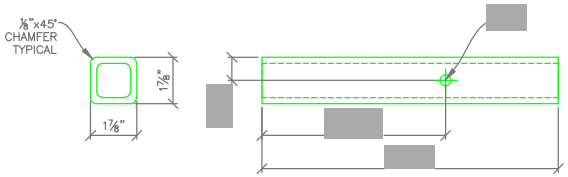


MK 3A - UHMW GUIDES FOR PILES
SCALE: NTS

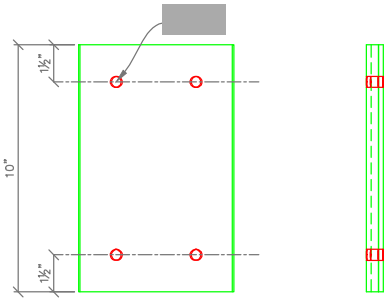




b2 - UHMW
SCALE: NTS



c2 - SQ T6061 ALUMINUM
SCALE: NTS



a6 - PLATE T6061 ALUMINUM
SCALE: NTS

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

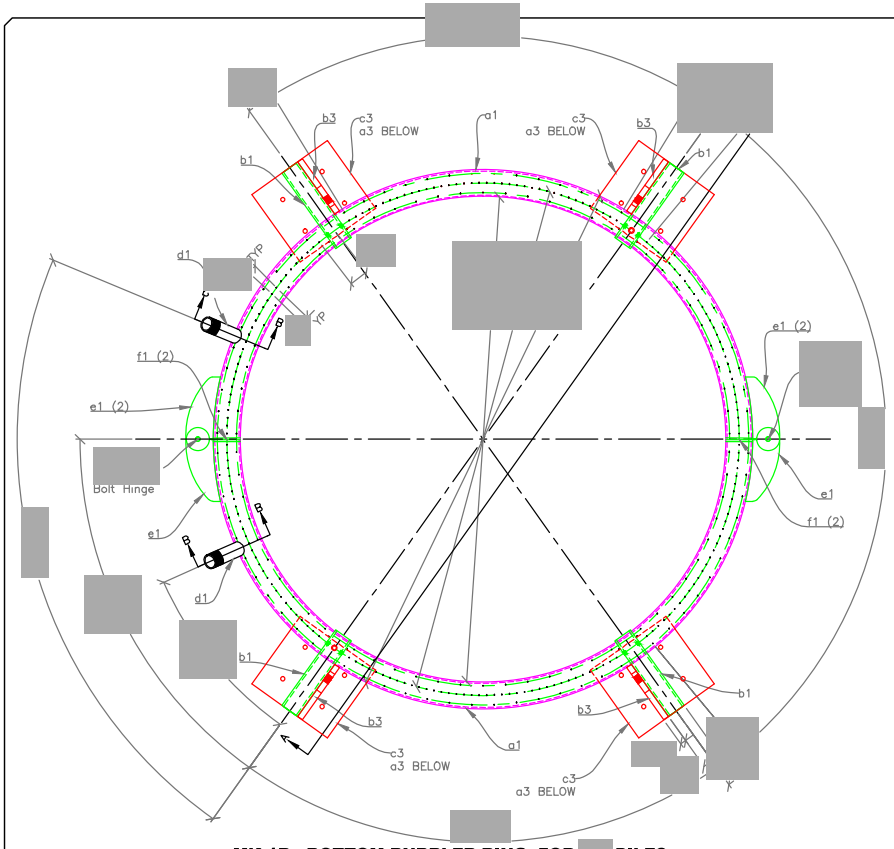
NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

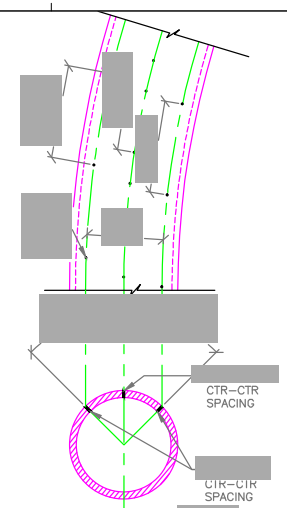
TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS

CONTRACT NUMBER: –
DATE: 5/19/13
DRAWING NUMBER: 4UBCR

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



MK 1B - BOTTOM BUBBLER RING FOR PILES
SCALE: NTS



TYPICAL SECTION - HOLE LAYOUT
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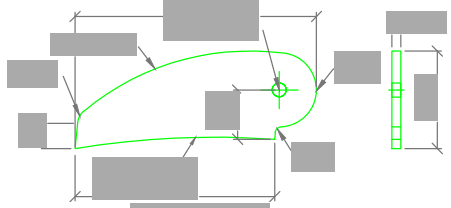

e1-PLATE T6061 ALUMINUM
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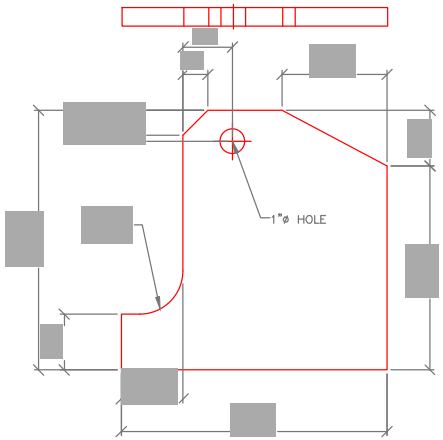

b3-PLATE - T6061 ALUMINUM
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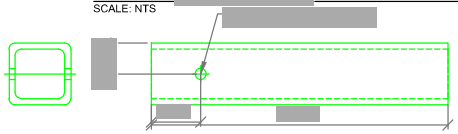

b1-TS T6061 ALUMINUM
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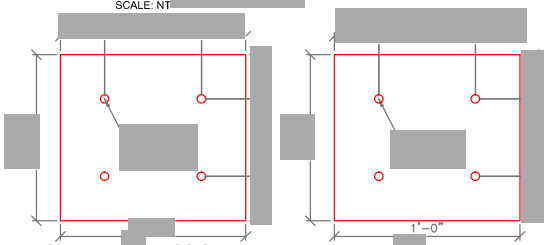
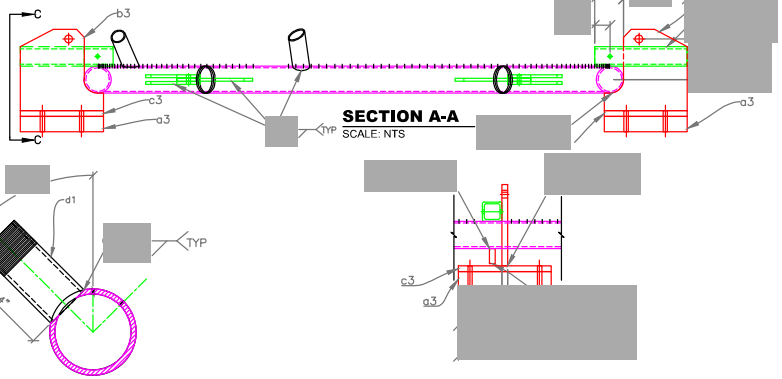


a3-PLATE - A36 STEEL
SCALE: NTS

c3-PLATE - T6061 ALUM.
SCALE: NTS



SECTION A-A
SCALE: NTS

SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS

SECTION C-C
SCALE: NTS

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

NEW YORK STATE THRUWAY AUTHORITY

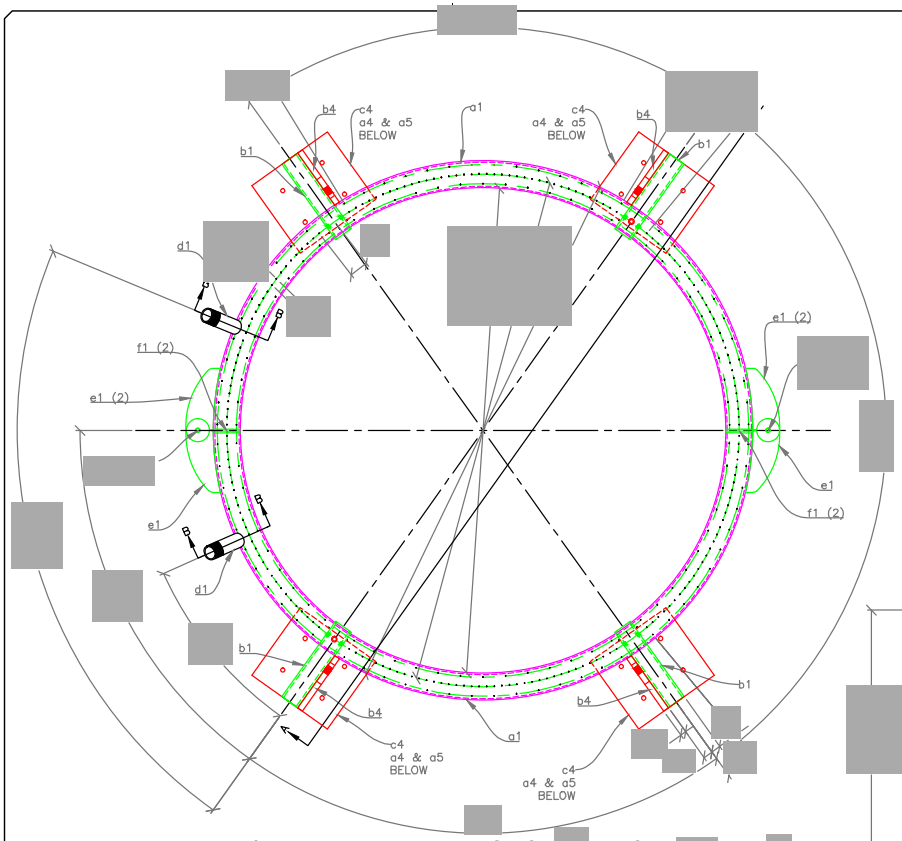
TAPPAN ZEE CONSTRUCTORS, LLC

TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS

CONTRACT NUMBER: -
DATE: 5/19/13
DRAWING NUMBER: 5UBCR

DOCUMENT TRACKING CODE: -

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



MK 1M - MIDDLE BUBBLER RING FOR PILES
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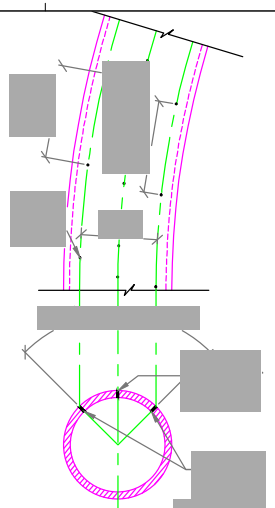
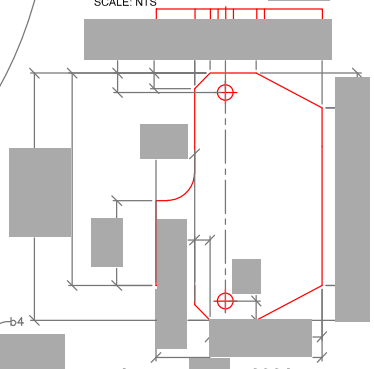
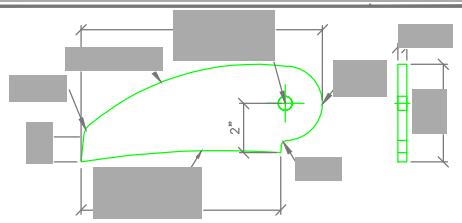


TYPICAL SECTION - HOLE LAYOUT
SCALE: NTS



b4-PLATE T6061 ALUMINUM
SCALE: NTS



e1-PLATE T6061 ALUMINUM
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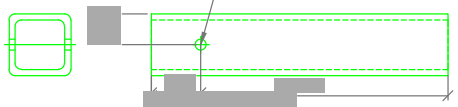

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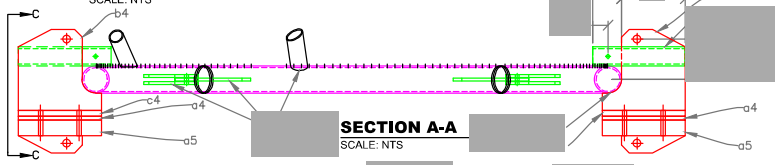
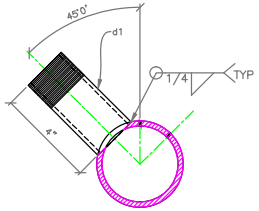
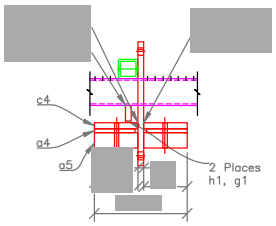
SCALE: N



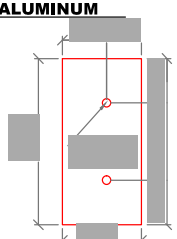
SECTION A-A
SCALE: NTS



SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS



SECTION C-C
SCALE: NTS



a4-PLATE A36 STEEL
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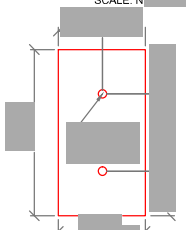
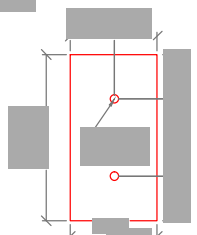


a5-PLATE A36 STEEL
SCALE: NTS



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
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS

CONTRACT NUMBER: –
DATE: 5/19/13
DRAWING NUMBER: 6UBCR

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

Atlas Copco