Description of Underwater Noise Attenuation System
Design Unit 8
for the
New NY Bridge Project

Revision 1
November 7, 2013

Prepared by
Tappan Zee Constructors, LLC

Document History			
Issue Date	**Description**	**By**	**Revision**
11/5/2013	Issued to NYSDEC for permit condition 9.		0
11/7/2013	Responded to NYSTA comments.		1

Table of Contents

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 Tappan Zee Hudson River Crossing project requirements:

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

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

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

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

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 this report is to provide the results of the underwater noise monitoring of the installation of test piles for the Design Unit 8 (see Attachment 1) and based on those results, provide the design plans and anticipated operational specifications for the noise attenuation system for Design Unit 8 in accordance with the following NYSDEC Permit requirements:

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

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

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

2.0 Installation of Test Piles

The Pile Load Test Program utilizes test piles in each of the ten (10) Design Units plus the Main Span (eleven [11] total design units), with the primary purpose to confirm pile load capacities. Design Unit 8 consists of piers 34 to 38. The foundation for pier 34 will consist of [redacted] piles while the foundations for pier 35 to 38 will consist of [redacted] piles. The installations of test piles were completed with an IHC S-800 impact hammer. PLT 113S did not require impact hammering, as the weight of the S-800 hammer drove the pile down to target depth. This pile is listed in Table 1 but is not included for subsequent NAS analysis. A summary of test pile installations for Design Unit 8 is provided in **Table 1**.

Table 1. Summary of Test Pile Installation for the NAS for Design Unit 8

Test Pile	Pile Diameter	Impact Hammering Date
PLT 112L	[redacted]	7/31/2013
PLT 112	[redacted]	8/3/2013
PLT 112RE	[redacted]	9/16/2013
PLT 113	[redacted]	9/21/2013
PLT 113S	[redacted]	N/A*

*PLT 113S sunk under the weight of the hammer.

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, Drawings 1UBCR through 10UBCR, for engineering details on the system.

3.1.1 NAS Components

The unconfined multi-tier bubble curtain consists of aluminum bubbler rings suspended from the pile-driving template at four points, spaced a maximum of 10 feet vertically, and connected to each other using ½"-diameter wire rope. See Attachment 2 for bubbler ring dimensions and details including hole diameter, spacing, and orientation for the NAS [redacted]

Rather than connecting multiple rings to a single larger compressor and having one ring receiving more air than the rest, each ring was connected to its own compressor (Figures 1). Each compressor was connected to a reservoir tank to allow a continuous supply of air throughout pile driving (Figure 2). During the installation of test piles, a flow meter and air pressure gauge were used to measure air flow and air pressure (Figure 3). However, the air flow meter will not be available during production pile driving. The air compressor is capable of supplying an air pressure of up to 100 pounds per square inch (psi) or an air flow of 1600 cubic feet per meter (cfm) to each bubbler ring (Attachment 3). However, because of the reservoir tank, the system is capable of supplying an air flow of up to 2000 cfm, to each bubbler ring, as was observed during testing.

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

Figure 2. Reservoir Tanks on the Air Compressor Barge

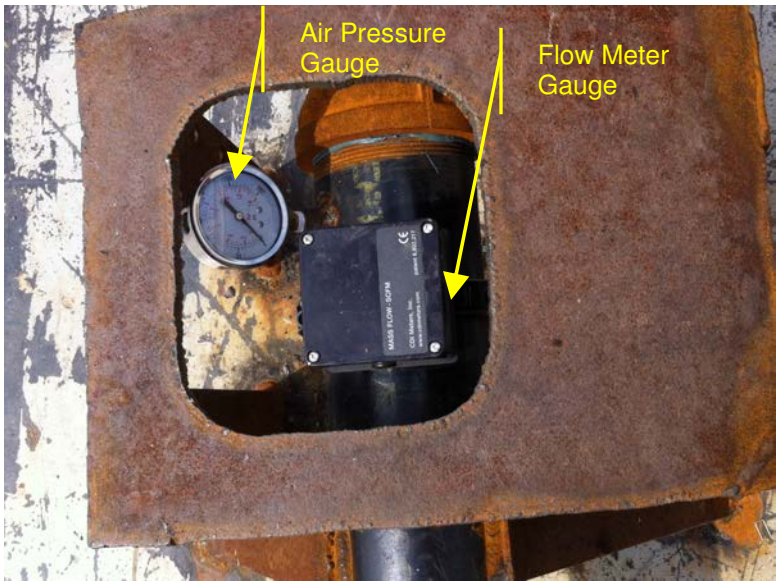


Figure 3. Flow Meters and Pressure Gauges on Outlets from the Reservoir Tank to the Bubbler Rings

3.1.2 NAS Deployment and Operation

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

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

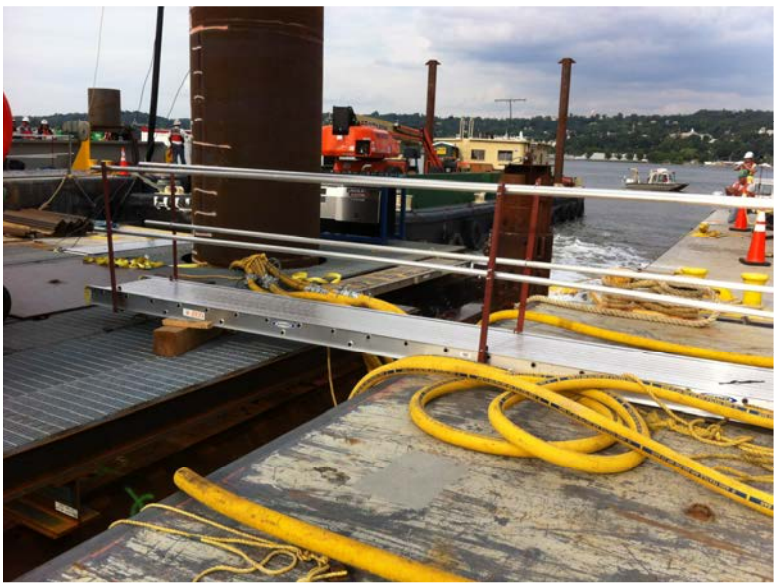


Figure 5. Operation of the Multi-Tier Bubble Curtain

4.0 Underwater Noise Monitoring During Test Pile Installation

4.1 Methods

Details of the equipment, the calibration of the equipment, the data collected, and the signal processing for underwater monitoring are included in the Underwater Noise Monitoring Plan. Details on the underwater noise monitoring for PLT 112L, PLT 112, PLT 112RE, and PLT 113 are provided in the Daily Memoranda for each day of pile driving (Attachment 1).

Figure 6a and Figure 6b depict the typical barge and hydrophone set up for [redacted] piles. As illustrated in Figure 6a and Figure 6b, a real time Autonomous Multichannel Acoustic Recorder (AMAR-RT) and several Autonomous Multichannel Acoustic Recorders (AMARs) were generally placed at the distances of the noise level thresholds predicted in the NMFS BO (although locations varied based on conditions, such as vessel traffic and tides). The AMAR-RT was continuously monitored through-out pile installation while data collected from the AMARs was downloaded following piling. The noise level thresholds predicted in the NMFS BO are as follows:

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

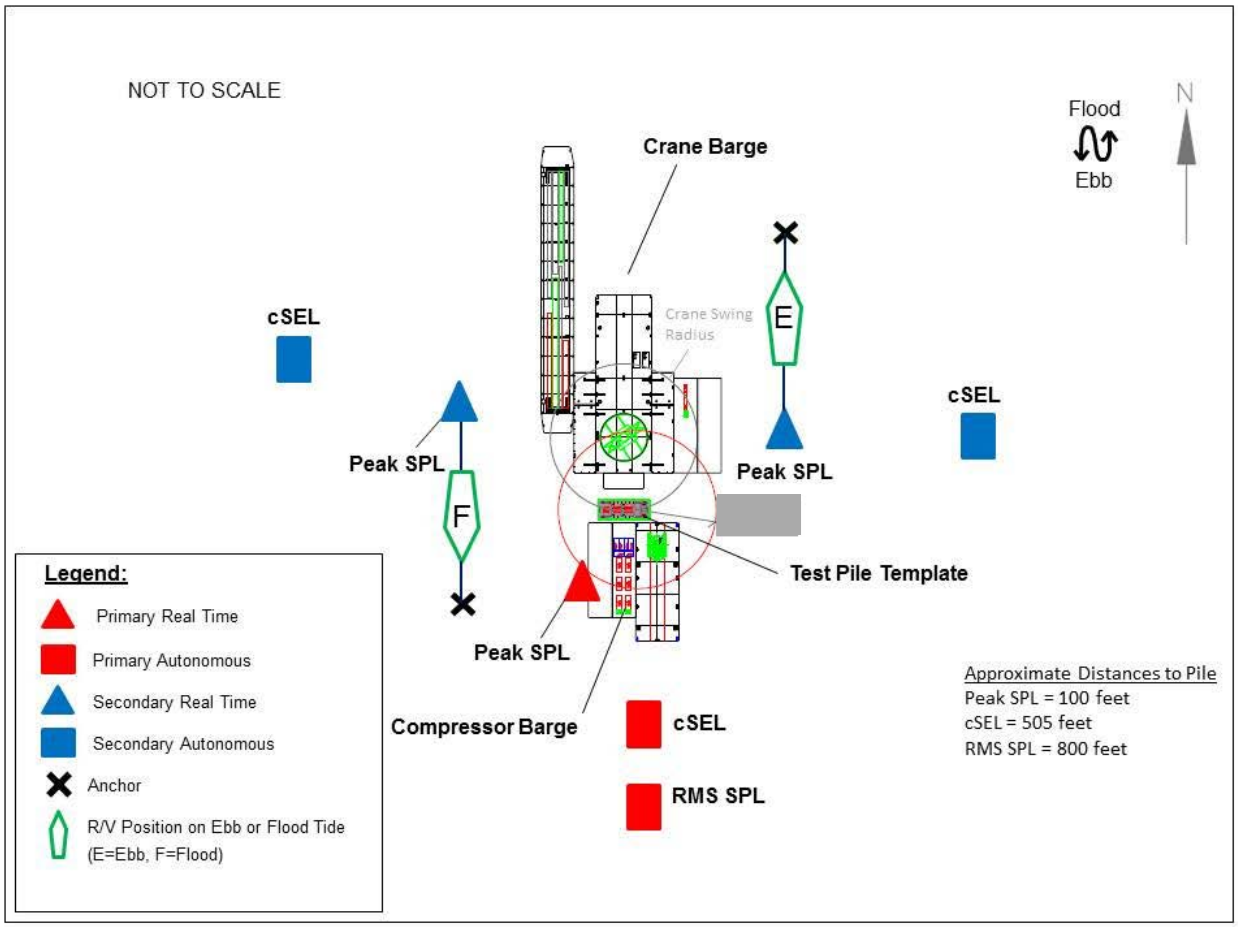


Figure 6a. Plan View of a Typical Test Pile Barge Arrangement and Hydrophone Locations for [redacted] Piles

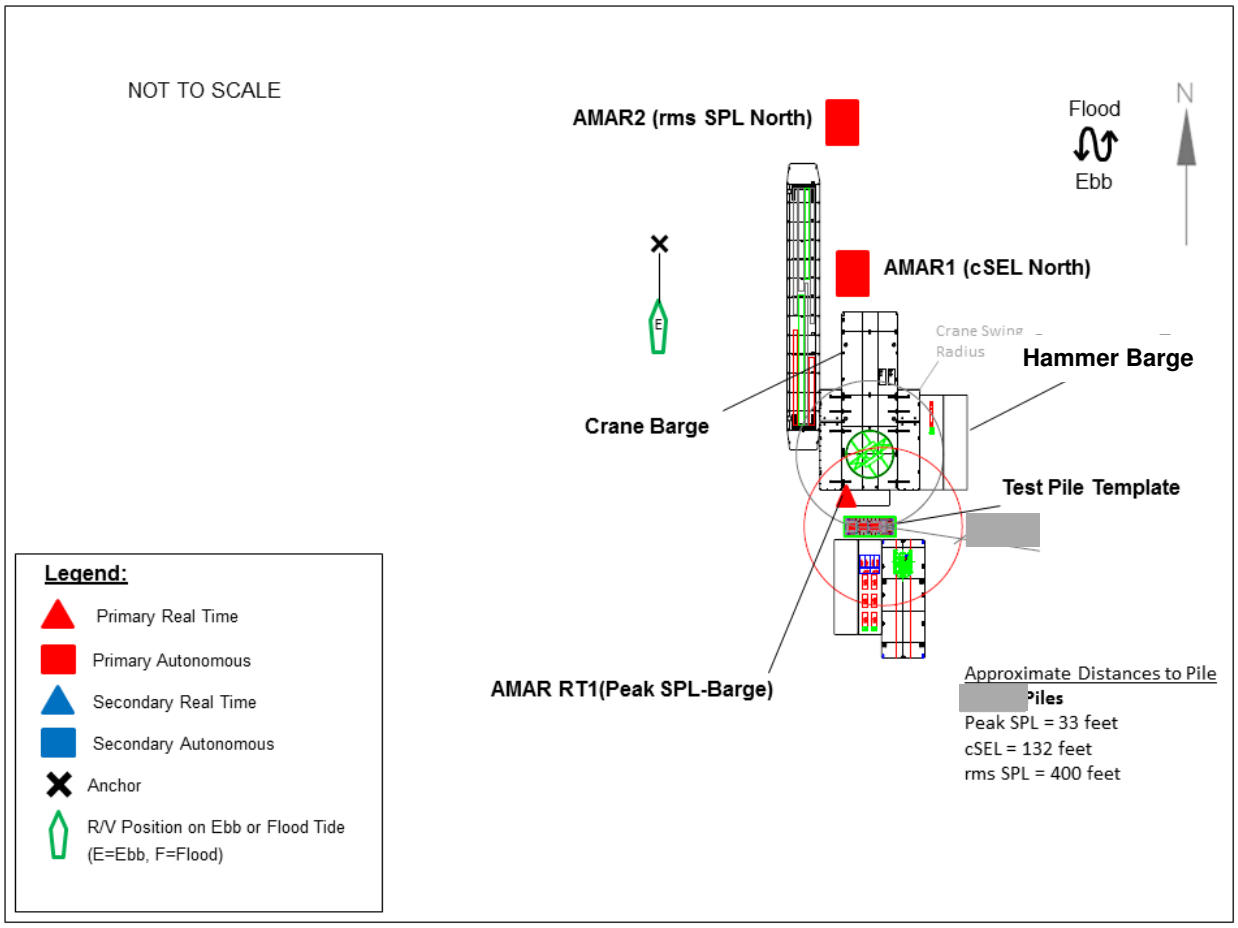


Figure 6b. Plan View of a Typical Test Pile Barge Arrangement and Hydrophone Locations for Piles

Test pile installation for Design Unit 8 occurred during a variety of current conditions (ebb, flood, and slack tide). Hydrophones were placed to capture variation in the performance of the NAS relative to the river current and barge placement.

During the installation of PLT 112L the currents were1-2 knots in a flood tide. The hydrophones were located up current and cross current at a several ranges. PLT 112 was installed during an ebb current of 1 to 1.5 knots. The hydrophones completely surrounded the test pile during PLT 112 to test the NAS in all directions. PLT 112RE was installed during an ebb current of 1-2 knots and all hydrophones were placed in up current positions. PLT 113 was installed during a 0-1.0 knot flood tide with hydrophones in up-current and down-current positions. Table 2 provides a summary of the underwater noise monitoring equipment deployment and position relative to the current for the driving of the test piles associated with Design Unit 8.

Table 2. Equipment Deployment and Position Relative to Current During Installation of Test Piles for Design Unit 8

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)
7/31/2013 PLT 112L	AMAR-RT 11	Peak SPL- Barge	Up-current	Flood tide (1 – 2 knots)	95	40
	AMAR-RT 12	Peak SPL- Vessel	Cross-current		270	31
	AMAR-221	cSEL South	Up-current		556	41
	AMAR-222	cSEL East	Cross-current		598	20
	AMAR-228	RMS SPL East	Cross-current		776	18
8/3/2013 PLT 112	AMAR-RT 11	Peak SPL- Barge	Down-current, position 1	Ebb tide (1 – 1.5 knots)	100	40
	AMAR-RT 12	Peak SPL- Vessel	Cross-current		170	34
	AMAR-221	cSEL East	Cross-current		282	31
	AMAR-222	cSEL North	Up-current		365	36
	AMAR-228	cSEL South	Down-current		238	40
9/16/2013 PLT 112RE	AMAR-RT-11	Peak SPL Barge	Up-current	Ebb tide (1-2 knots)	34	38
	AMAR-175	cSEL North	Up-current		304	36
	AMAR-228	rms SPL North	Up-current		581	36
9/21/2013 PLT 113	AMAR-RT 11	Peak SPL- Barge	Up-current	Flood tide (0 – 1.0 knots)	46	9
	AMAR-175	cSEL North	Down-Current		148	9
	AMAR-228	rms SPL North	Down-current		772	10

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

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

**At the completion of pile driving.

In order to test the performance of the NAS, air flow was varied from 900 to 2000 cfm and air pressure from 35 to 80 psi throughout the installation of PLT 112L and 112. The NAS system was operated at 70 psi (1250-1400 cfm) during the installation of PLT-112RE. The NAS system was operated at an air pressure of 40-42 psi (1050-1100 cfm) during installation of PLT 113. Table 3 provides operation of the NAS during the installation of the test piles.

Table 3. Description of NAS During Installation of Test Piles for Design Unit 8

Date/ Test Pile No.	Water Depth (ft)	Number of Rings	Air Flow (cfm) per Bubbler Ring	Air Pressure (psi)
7/31/2013 PLT 112L	42	5	900-2000	35-80
8/3/2013 PLT 112	42	5	900-2000	40-70
9/16/2013 PLT 112RE	38	5	1250-1400	70
9/21/2013 PLT 113	10	1	1050-1100	40-42

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, (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.

Tables 4 provides a summary of the underwater sound levels measured at each recorder during the test pile installation. Table 5 provides the distances to each of the NMFS BO thresholds. **These results show that the diameter of the 206 dB re 1 µPa peak SPL did not exceed NMFS requirement of 200-ft for [redacted] piles and 40-ft for [redacted] piles at Design Unit 8.** The distance to the 206 dB re 1 µPa peak SPL isopleth was 7.5-ft for [redacted] and 7.6-ft for [redacted] which is similar to the 206 dB re 1 µPa peak SPL results for the NASs tested during the 2012 PIDP. Specifically, during the 2012 PIDP the distances to the 206 dB re 1 µPa peak SPL isopleth was 7.5 – 20 ft for [redacted] piles, 37.8 ft for the [redacted] pile, and 14.4 ft for the 10-ft pile (Jasco 2012)[2].

Furthermore, the estimated diameter of the 187 dB re 1 μPa^2-s cSEL isopleth at the end of installation of test piles never exceeded 100-ft for [redacted] piles and never exceeded 229 ft for [redacted] piles. The river width is approximately 15,000 ft; therefore a fish movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving, in accordance with New York State Department of Environmental Conservation Permit Condition 14.

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

Table 4. Summary of the Measured Sound Levels at Each Hydrophone During the Installation of Test Piles for Design Unit 8

Date/ Test Pile No.	Location*	Distance to Pile (ft)	Max. peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^{2-}s)**
7/31/2013 PLT 112L	Peak SPL- Barge	95	180	180
	Peak SPL- Vessel	270	171	166
	cSEL South	556	169	170
	cSEL East	598	163	159
	RMS SPL East	776	157	150
8/3/2013 PLT 112	Peak SPL- Barge	100	182	185
	Peak SPL- Vessel	170	180	179
	cSEL East	282	179	176
	cSEL North	365	180	175
	cSEL South	238	175	177
9/16/2013 PLT 112RE	AMAR-RT-11	34	202	197
	AMAR-175	304	184	174
	AMAR-228	581	171	168.4
9/21/2013 PLT 113	Peak SPL- Barge	46	192	198
	cSEL North	148	191	190
	rms SPL North	772	172	174

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

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

**At the completion of pile driving. .

Table 5. Estimated Distance from Design Unit 8 Pile Driving to the Noise Levels that Represent NMFS Thresholds

Measurement		PLT 112L	PLT 112	PLT 112RE	PLT 113
Pile Installation Duration (hh:mm:ss)		00:04:27	00:26:00	00:15:19	00:25:00*
Approximate Distance in Feet to Threshold	206 dB re 1 µPa peak SPL	8	<3	8	8
	187 dB re 1 µPa^2-s cSEL	53	95	92	229
	150 dB re 1 µPa rms SPL	355	462	392	929

*Value estimated based on rms SPL North plot for PLT 113 (see Attachment 1).

4.2.2 NAS Performance

4.2.2.1 NAS Performance

The NAS was tested in flood and ebb tides, with hydrophones at various locations relative to the current (i.e., cross current, up current, and down current) (Table 2a). Current speed ranged from 1 to 2 knots.

Results over all three piles were variable. No patterns were detected based on location of the recorder relative to current. Measured sound levels for PLT112L were slightly higher at the 500-600 ft up current recorder compared to the 500-600-ft cross current recorder during a flood tide (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 112L). Changes in tidal state fromthe ebb to slack tide did not appear to affect sound levels for PLT 112 (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 112). In all cases, the NAS proved to be effective at attaining the required NMFS threshold of 206 dB re 1µPa peak at 100-ft during all tide conditions.

Air flow varied from 900 to 2000 cfm and air pressure from 35 to 80 psi throughout the installation of three 6-ft test piles. Insufficient data was collected during the installation of PLT 112 for a reliable statistical analysis of the NAS air flow settings. Air flow was never altered independently of other variables, such as increased hammer energy or tidal condition during the installation of PLT 112. At PLT 112, sound levels appear to be negatively correlated with the NAS air flow (measured sound levels increased as air flow decreased) or positively correlated with the strikes per foot (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 112). However, the NMFS threshold of 206 dB re 1µPa peak at 100-ft was not exceeded despite variation in air flow.

At PLT 112RE air flow remained relatively constant at 1250-1400 cfm (70 psi) during a 1-2 knot ebb and sound levels decreased through the duration of pile driving (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 112RE). The NMFS threshold of 206 dB re 1µPa peak at 100-ft was not exceeded even for the two-minute period with the highest sound levels (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 112RE).

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

4.2.2.2 NAS Performance for

The NAS was tested in a flood and slack tide with hydrophones located up-current and down-current relative to the current (Table 2b). Current speed ranged from 0 to 1.0 knots. The NMFS 206 dB re 1µPa peak SPL 40-ft diameter isopleth was not exceeded during the driving of PLT 113. Air flow was relatively

constant at 1050 to 1100 cfm (40-42 psi) throughout the installation of PLT 113. Hammer energy was increased independently of river current and NAS air flow. Hammer energies of 160, 250, 310 and 365 kip-ft were used (Attachment 1: Daily Memorandum for Underwater Noise Monitoring for PLT 113). At all measurement locations the measured sound levels tended to increase during the pile driving. However, the thresholds required by the NMFS BO and NYSDEC permit were not exceeded.

Sound levels measured 148 ft from the pile (Table 4a, Table 4b) were responsible for the increased range to the 187 dB re 1 $\mu Pa^2 \cdot s$ isopleth compared to other PLT measurements (Table 5a, Table 5b). The mechanism that caused this sound level increase is unknown.. There is no indication that this effect would cause the sound levels to exceed the NMFS and NYSDEC permit thresholds.

4.3 Conclusions

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

Results of test pile installation indicate that the sound levels due to pile driving with [redacted] piles with the IHC S-800 hammer and an unconfined multi-tier bubble curtain do not exceed the NMFS and NYSDEC permit requirements. Not only did the system meet the requirements in various tidal conditions and positions relative to the current, as well as for the various NAS settings evaluated the, underwater sound was reduced beyond NMFS and NYSDEC requirements. Results indicate that the 206 dB re 1µPa peak SPL isopleth was constrained to distances of 8 ft for [redacted] piles and [redacted] diameter piles at Design Unit 8 test pile locations. That is, the largest estimated width of the 206 dB re 1µPa peak SPL isopleth was measure at 16 ft, as compared to the 200-ft for [redacted] piles and 40-ft for [redacted] piles predicted by the NMFS BO. These results indicate that 'the radii of the 206 dB re 1 µPa isopleth measured for the [redacted] piles in 40-ft to 10-ft of water with the multi-tier bubble curtains were smaller than any of the radii 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 229 ft. Therefore, the majority of the width of the river at the construction site would be an acoustic-free movement corridor for fish.

5.0 NAS Design Plan and Operational Specifications

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

During production pile driving for Design Unit 8, the unconfined multi-tier bubble curtain will be deployed and retrieved in a similar manner to the PLT 112L, 112, 112RE, and 113 pile installation. Water depth was approximately 42-ft for PLT 112L, 112, and 112RE and approximately 9-ft for PLT 113. Two bubble curtain rings will be deployed for every 8 to 10 feet of water depth. Table 6 provides the range of water depths at each Design Unit 8 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 8 Pier and the Number of Bubble Curtain Rings to be Deployed

Pier	Approximate Water Depth (feet)	Number of Bubble Curtain Rings
34	16-18	2
35	10-12	2
36	10-12	2
37	10-12	2
38	10-12	2

The NAS system contains three valves at the:

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

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

The following will be checked for each of the piles at each pier within Design Unit 8 (as outlined in the Construction Work Plan):

- Reservoir tank is pressurized prior to pile driving.
- The tank inlet and outlet valves are open immediately prior to pile driving.
- Air pressure at each reservoir tank outlet approximately 5 minutes after pile driving begins.

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

Figure 8. Valve at the Reservoir Tank Inlet

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

Figure 10. Air Compressor Controls

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

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

Daily Memorandum for 31 July 2013

Submitted to:

[redacted]

Authors:

[redacted]

JASCO Applied Sciences

[redacted]

31July 2013

P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-112L is a [redacted] pile driven at the site of the New NY Bridge on the east side of the navigation channel on 31 July 2013 (Table 1). Two real-time acoustic monitoring systems and three autonomous acoustic monitoring systems were deployed by JASCO (Section 0) on behalf of Tappan Zee Constructors, LLC (TZC) to measure sound levels at ranges of 95–776 ft from the pile (Figure 1, Table 2). Pile driving occurred between 17:57–18:57 Eastern Daylight Time (EDT), and full flood tide occurred at 18:02 EDT.

The real-time systems were located 95-ft south of the pile and 270 east of the pile. The three autonomous systems were south and east of the pile at ranges of 556 ft, 598 ft, and 776 ft.

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 (SELs), and sound level statistics for the distribution of the measured data are presented in Appendix A.

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

Date:	31 July 2013
Pile-Driving Activity	
Test pile identifier:	PLT-112L
Pile diameter:	[redacted]
Water Depth	42 ft
Hammer type:	Impact (IHC S-800)
Total hammer strikes:	198
Total penetration:	187 ft
Net duration of pile driving (hh:mm:ss):	00:04:27
Maximum single strike energy:	169 thousand foot-pounds (kip-ft), (229 kJ)
Total energy transferred:	28788 kip-ft (39.1 MJ)
Noise Attenuation System	
Five-tier unconfined bubble curtain airflow rate:	900–2000 cubic feet minute (cfm), 35–80 pounds per square inch (psi)
River conditions during piling:	Flood tide, 1–2 knots (0.5–1 m/s), depth dependent; Table 7, Figure 5)

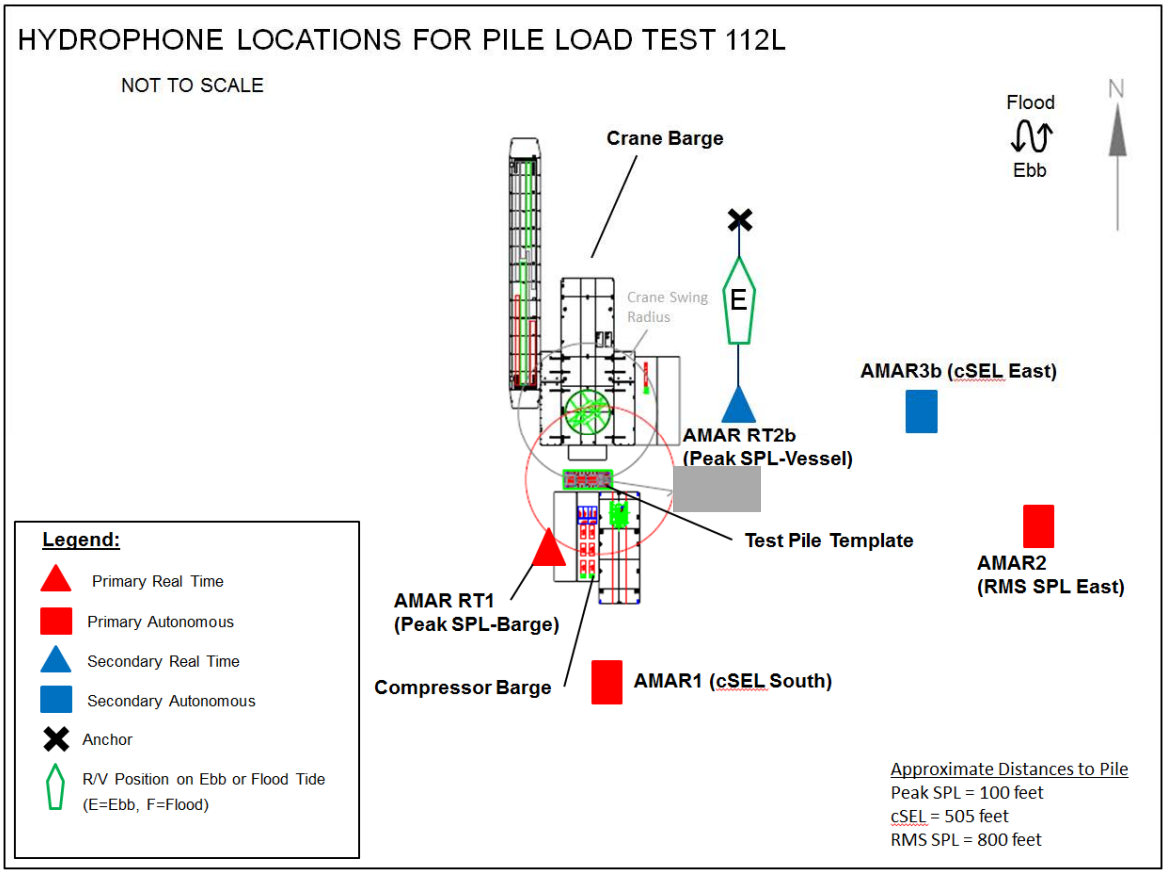


Figure 1. Plan view of pile and barge layout, 31 July 2013, PLT-112L.

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

Location	Recorder ID	Distance to pile (ft)	Water depth (ft)	Max. peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^{2}s*)
Peak SPL Barge (up current)	AMAR-RT-11	95	40	179.8	180.6
Peak SPL Vessel (cross current)	AMAR-RT-12	270	31	170.5	166.3
cSEL South (up current)	AMAR-221	556	41	169.1	170.3
cSEL East (cross current)	AMAR-222	598	20	164	160.1
rms SPL East (cross current)	AMAR-228	776	18	157.3	150.8

* 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), rms SPL, and single strike sound exposure levels (SELss) from each recorder (

Table 3 and Figure 2).

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was approximately 15 ft, and did not exceed NMFS criteria of a diameter of 200 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 110 ft at the end of pile driving. Since cSEL increases as the number of strikes increases, the diameter of the 187 dB isopleth was smaller than 110 ft for most of the pile driving operation. No other pile driving occurred during this pile load test. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

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

Criteria	Estimated Radius (ft)
206 dB re 1 µPa peak SPL	7.5
187 dB re 1 µPa2·s cSEL*	55*
150 dB re 1 µPa rms SPL (one second integration time)	364

* At the end of pile driving

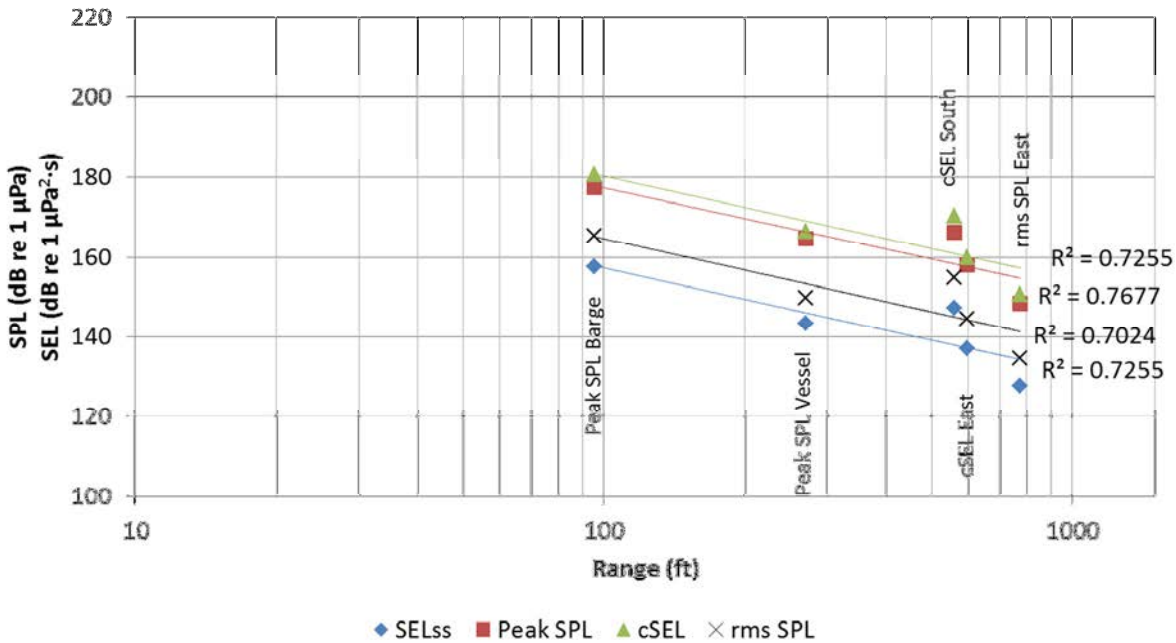


Figure 2. Regression based on mean values of the peak SPL, rms SPL, and single strike SELs from each recorder from pile driving of Test Pile PLT-112L, 31 July 2013. Single Strike SEL (SEL_{ss}), peak SPL, and rms SPL are instantaneous values. The cSEL represents total sound energy measured during the pile driving.

1.3. Observations

The impact hammer was operated at a hammer energy 150+/-15 kip-ft (Figure 4). The majority of the strikes at PLT-112L occurred between 17:57-18:06 (Figure 4), which was at the time of full flood currents for 31 July 2013 (Figure 5). The ADCP measurements showed flood (northerly) currents of up to 2 knots (1 m/s) at depths of 4–18 ft. The autonomous recorder at location cSEL South was directly upstream of the pile at a distance of 560 ft. It recorded sound levels that were higher than the autonomous recorder at location cSEL East, which was cross current from the pile driving at a range of 598 ft (see Table 2). The differences between the median sound levels measured at cSEL South and cSEL East were(Figure 2, Table 2, Figure 11, Figure 13):

- rms SPL: 11.4 dB,
- peak SPL: 5.1dB, and
- cSEL: 10.2 dB.

The recorder at location cSEL South was at a water depth of 41 ft and cSEL East was at a water depth of 20 ft. Therefore, two possible variables that may explain the difference in sound level are differences in NAS performance due to orientation to the current and bathymetry. Since cSEL South had sound levels that were not well represented by the linear regression in Figure 2, a regression that excludes cSEL South should be performed. The regression analysis without cSEL South generates R^2 values much closer to 1 indicating that the data are more accurately represented by the linear regression (Figure 3, Table 4). The regression without cSEL South has

recorders at depths of 40, 31, 20 and 18 feet. This strongly suggests that orientation to the current affected NAS effectiveness which increased the measured sound levels.

The recorder at location Peak SPL Barge was also up current of the pile at a range of 95 ft, yet its data fit the regression well (Figure 3). The flood currents at Tappan Zee Bridge run at 356° True. The bearing from Peak SPL Barge to PLT 112L was 051° True (55° to the current) whereas cSEL South to PLT 112L was a bearing of 005 ° True (10° to the current) It is likely that location Peak SPL Barge was sufficiently cross current that NAS effectiveness was not affected.

There is no indication that the required NMFS and NYSDEC thresholds were exceeded in any direction, regardless of the change in NAS effectiveness over a narrow angular region up current at full current flow (

Table 3, Table 4). The ranges to the 206 dB re 1 µPa (Peak) and the 187 dB re 1 µPa^2·s (SEL) isopleths are longer when only four recorders are included in the regression. This is due to the high levels at cSEL South decreasing the slope of the regression line which decreases the intercept estimates and hence the estimate isopleth ranges.

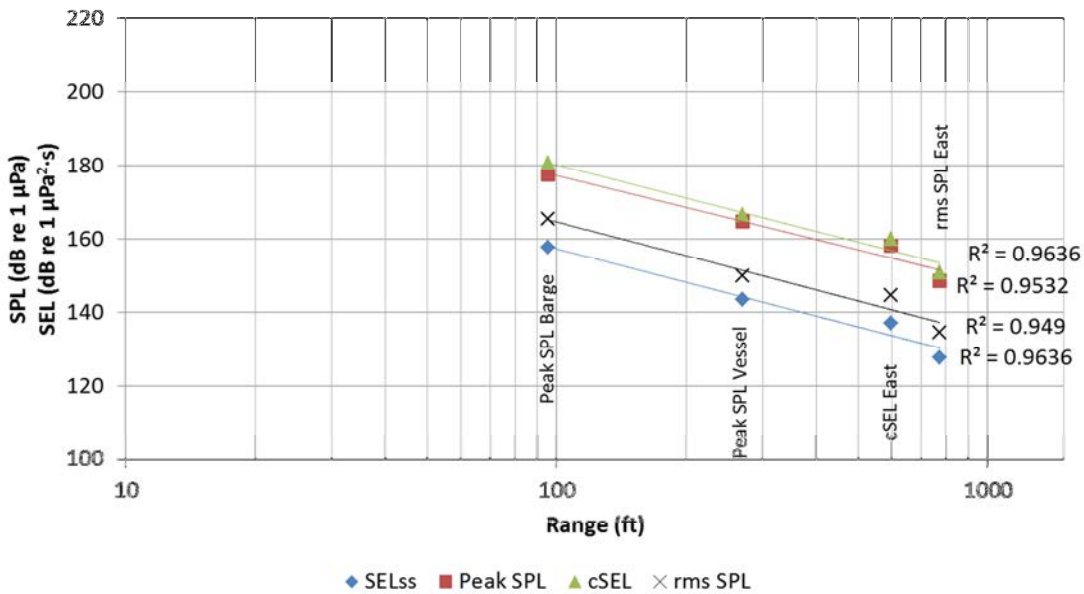


Figure 3. Regression based on mean values of the peak SPL, rms SPL, and single strike SEL from all recorders except cSEL South from pile driving of Test Pile PLT-112L, 31 July 2013. Single Strike SEL (SEL_{ss}), peak SPL, and rms SPL are instantaneous values. The cSEL represents total sound energy measured during the pile driving.

Table 4. Estimated isopleth radii for the NMFS physiological and behavioral thresholds.

Criteria	Estimated Radius (ft)
206 dB re 1 µPa peak SPL	10
187 dB re 1 µPa2·s cSEL*	59*
150 dB re 1 µPa rms SPL (one second integration time)	298

* At the end of pile driving

The distribution of 1/3-octave-band SEL plots (e.g. Figure 12) show how the measured sound levels were distributed in frequency. By selecting a one of the 1/3-octave-bands as a reference we can examine the difference in frequency content at each measurement location by examining how the other bands fluctuate compared to the reference. The peak bands near 10 Hz make a good reference since they are near the peak of the low frequency energy content at all locations (Figure 8, Figure 10, Figure 12, Figure 14, Figure 16). At location cSEL South the 1/3-octave-bands between 125 and 400 Hz are 10 – 16 dB above the levels at the low frequency peak. At the other locations they never exceed 10 dB. This provides evidence that the NAS is attenuating frequencies above 100 Hz better than frequencies below 100 Hz at this location.

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 5 provides activities for 31 July 2013.

Table 5. JASCO and construction activities for Test Pile PTL-112L, 31 July 2013.

Time (EDT)	Activity
08:45	Held safety meeting on shore
08:50	Perform hydrophone calibration on AMAR-RT
10:20	Transit to barge spread
10:25	Begin deploying AMARs
11:11	Complete all autonomous AMARs deployments
11:12	Standing by for impact hammering
14:13	Start vibratory hammering
15:30	Deploy AMAR-RT from Alpine vessel
16:10	Deploy AMAR-RT from barge
17:07	CTD cast from barge
17:56	Activate NAS
17:57	Start impact hammering
18:15	Stop main hammering
18:38	Begin retrieval of AMARs from Alpine vessel (ADCP shutdown)
18:57	Restrike pile 10 times; stop hammering
19:21	All AMARs retrieved
19:30	AMAR-RT retrieved
19:45	At dock; data downloaded, secured

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Five-tier unconfined bubble curtain

NAS settings: 900–2000 cfm, 35–80 psi

Table 6. NAS setting recorded during piling at Test Pile PLT-112L, 31 July 2013.

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

2.2.2. Impact Hammering Log

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

Total number of strikes: 198

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

Net piling duration (hh:mm:ss): 00:04:27

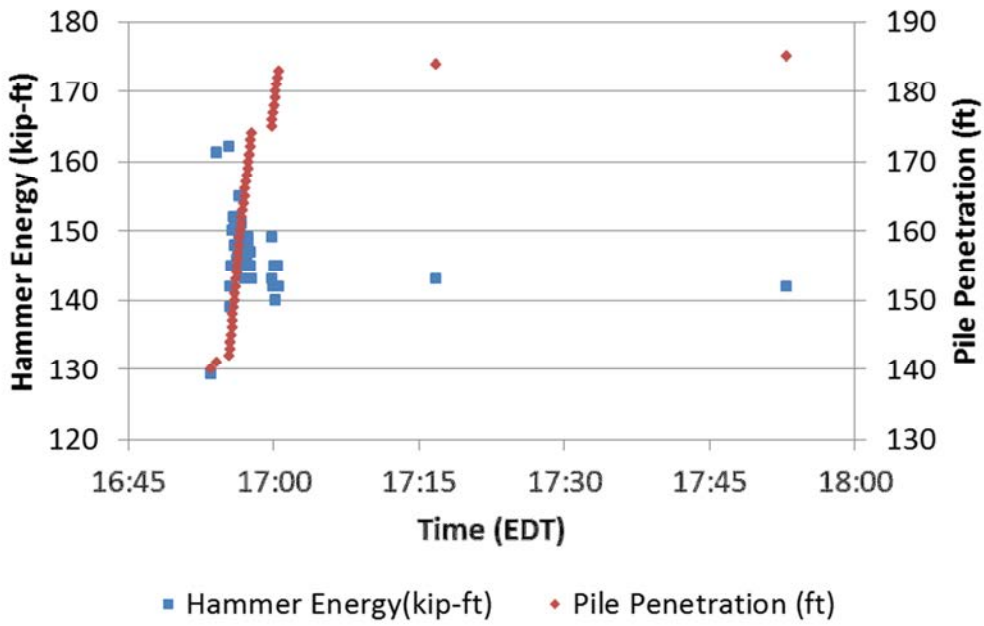


Figure 4. Hammer energy and pile penetration for the impact piling of PLT-112L, 31 July 2013

3. Weather and River Conditions

Table 7 and provide the predicted currents at the project site for 31 July 2013. Figure 5 provides the Acoustic Doppler Current Profiler (ADCP) measured currents. Figure 6 provides the measured speed of sound in water, based on a conductivity, temperature, depth (CTD) cast.

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

Weather conditions:	Sunny, wind gusts to 5 mph
Full ebb current:	12:03(1.6 knots)
Slack current:	14:47 (
Full flood current:	18:02 (1.1 knots)
Maximum ADCP-logged water depth	12 m
Minimum ADCP-logged water depth	12 m

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=

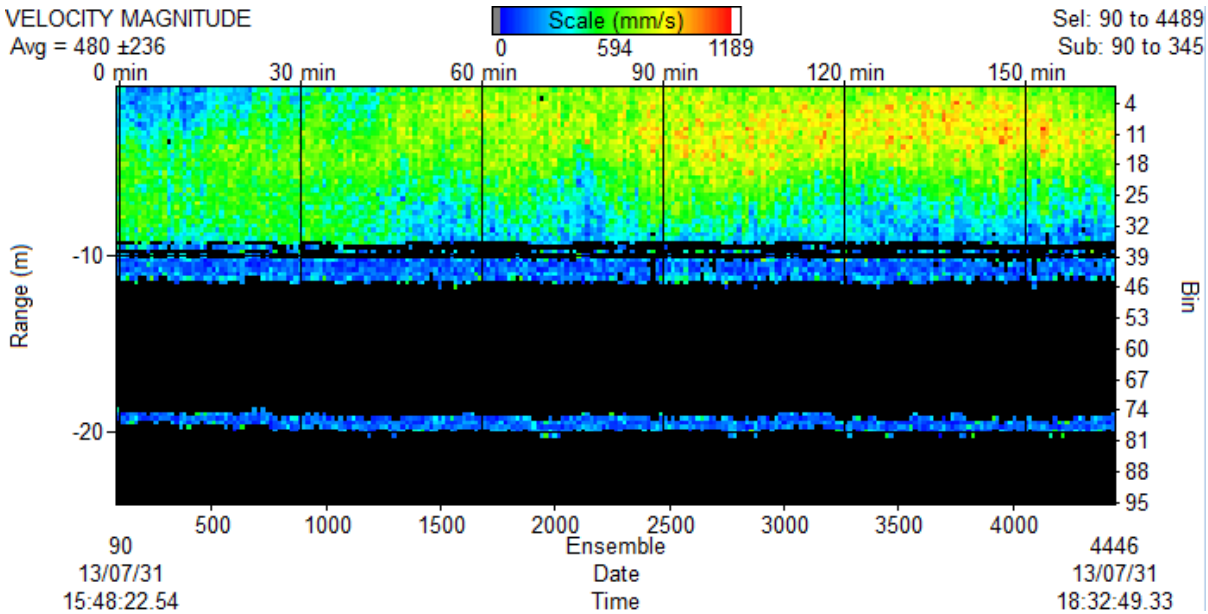


Figure 5. ADCP data from 31 July 2013 during pile driving. Times are in EDT.

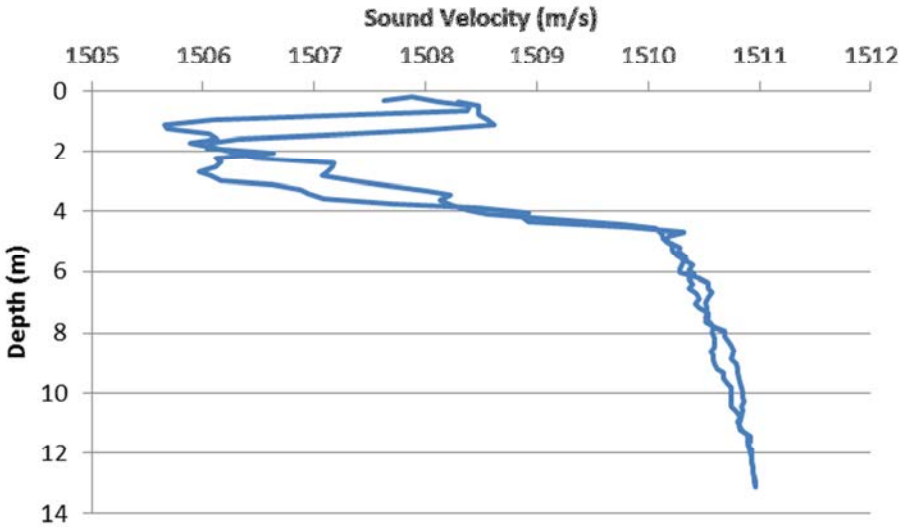


Figure 6. CTD cast performed at 17:07 EDT from the Alpine vessel, .

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 8 provides information on the real-time monitoring equipment used on 31 July 2013. Table 9 provides location information on the real-time recorder..

Table 8. AMAR-RT information for Test Pile PTL-112L, 31 July 2013.

Equipment used		Units deployed
Acoustic Data Logger		
Model:	AMAR RT (JASCO Applied Sciences)	2
SpectroPlotter version:	6.0.1	2
Hydrophone		
Model:	M8KC (GTI)	2
AMAR-RT-11 sensitivity:	–211.3 dB re 1 V/µPa	1
AMAR-RT-12 sensitivity:	–210.8 dB re 1 V/µPa	1
Other		
Hydrophone calibrator:	Pistonphone Type 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, 31 July 2013.

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

4.2. Autonomous Monitoring Equipment

Table 10 provides information about the autonomous monitoring equipment used on 31 July 2013. Table 11 provides the locations of the autonomous recorders..

Table 10. Autonomous recorder information for Test Pile PTL112L, 31 July 2013.

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

Table 11. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 31 July 2013.

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

Appendix A. Pile Driving Plots

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

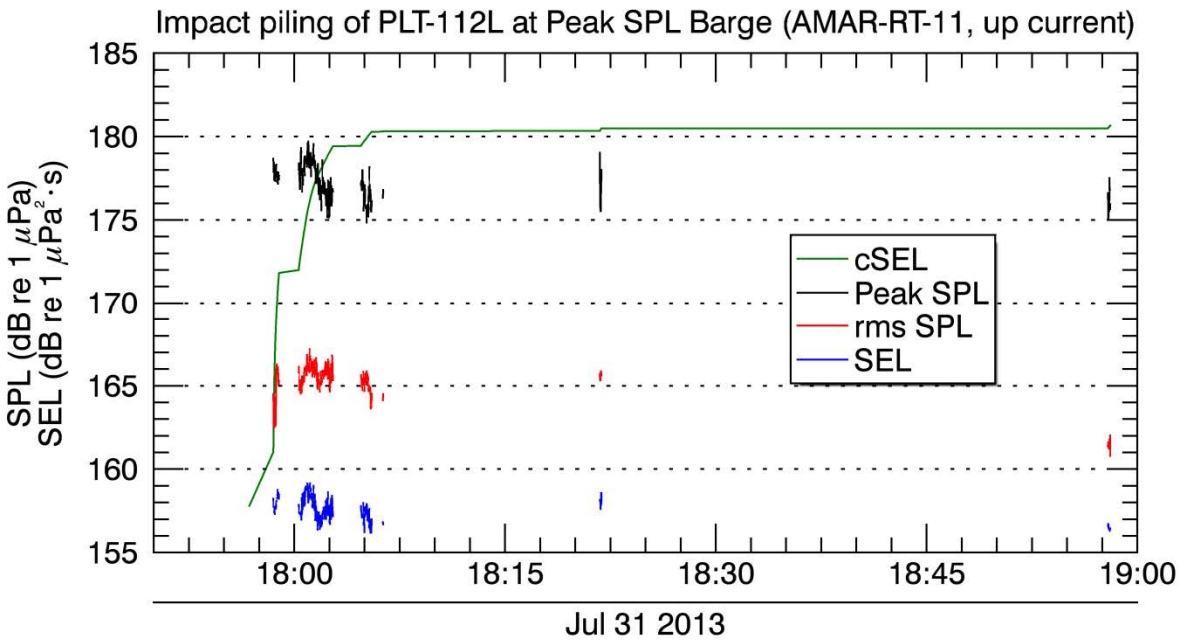


Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 95 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

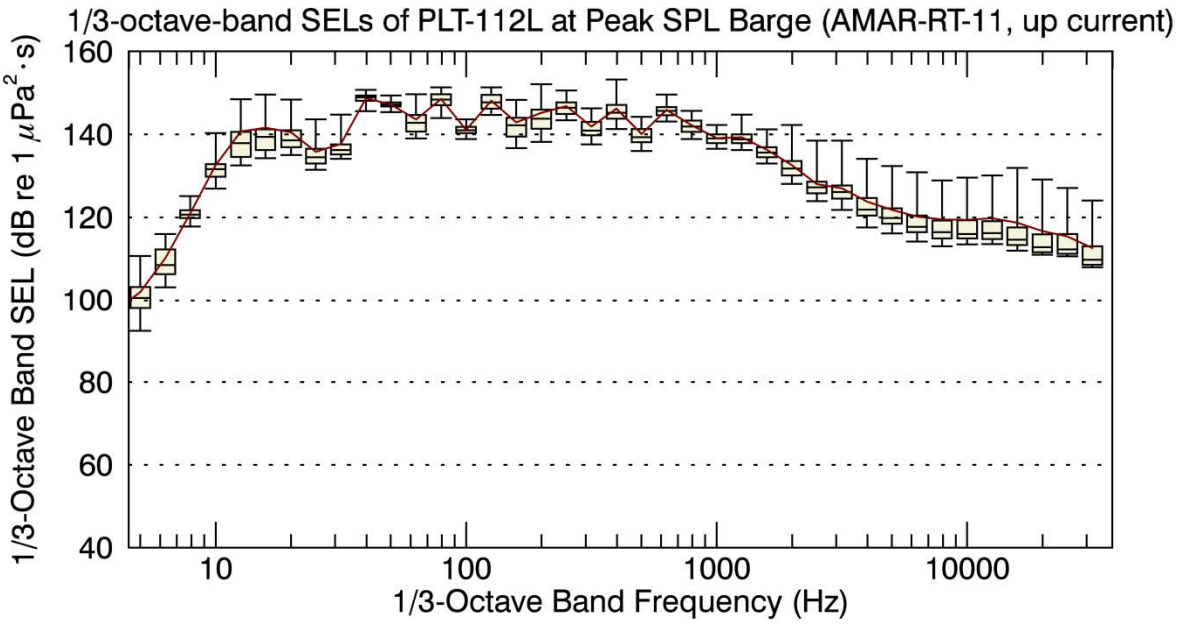


Figure 8. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112L measured 95.4 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 12. Sound levels for the pile driving of Test Pile PLT-112L measured 95.4 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)	Single strike SEL (dB re 1 µPa²s)
L_{max}	179.8	167.2	159.2
L_5	179	166.6	158.8
L_{25}	178.1	165.9	158.1
L_{50}	177.3	165.5	157.6
L_{75}	176.6	165	157.1
L_{95}	175.5	162.5	156.4
L_{mean}	177.4	165.4	157.7

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

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

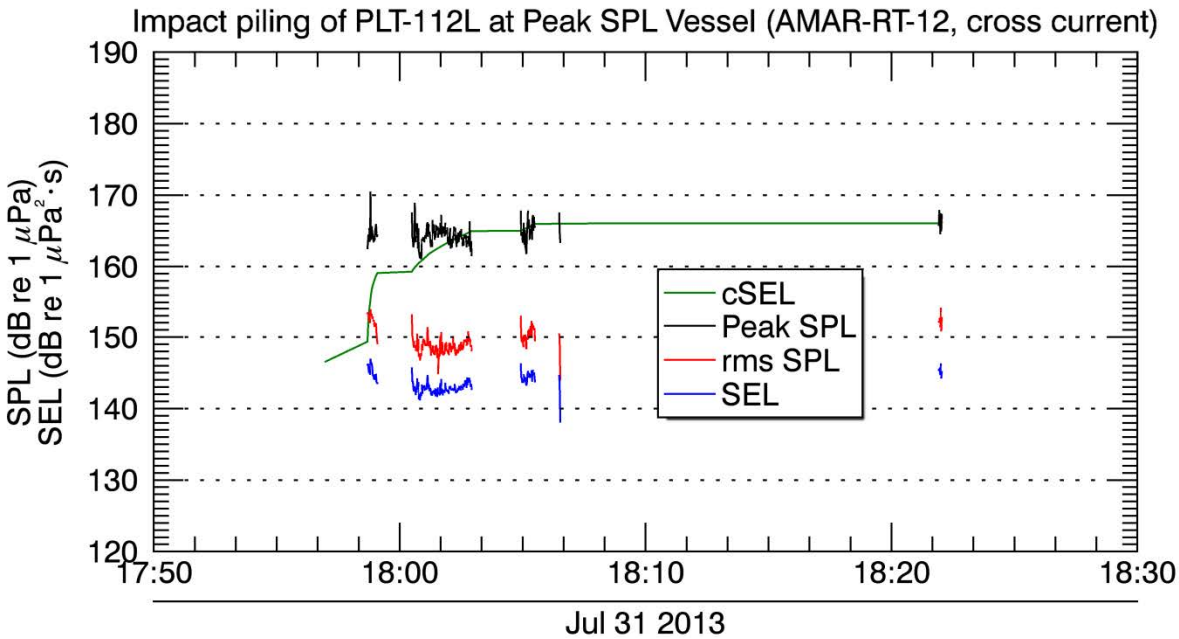


Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 270 ft from the pile at location Peak SPL Vessel using AMAR-RT-12.

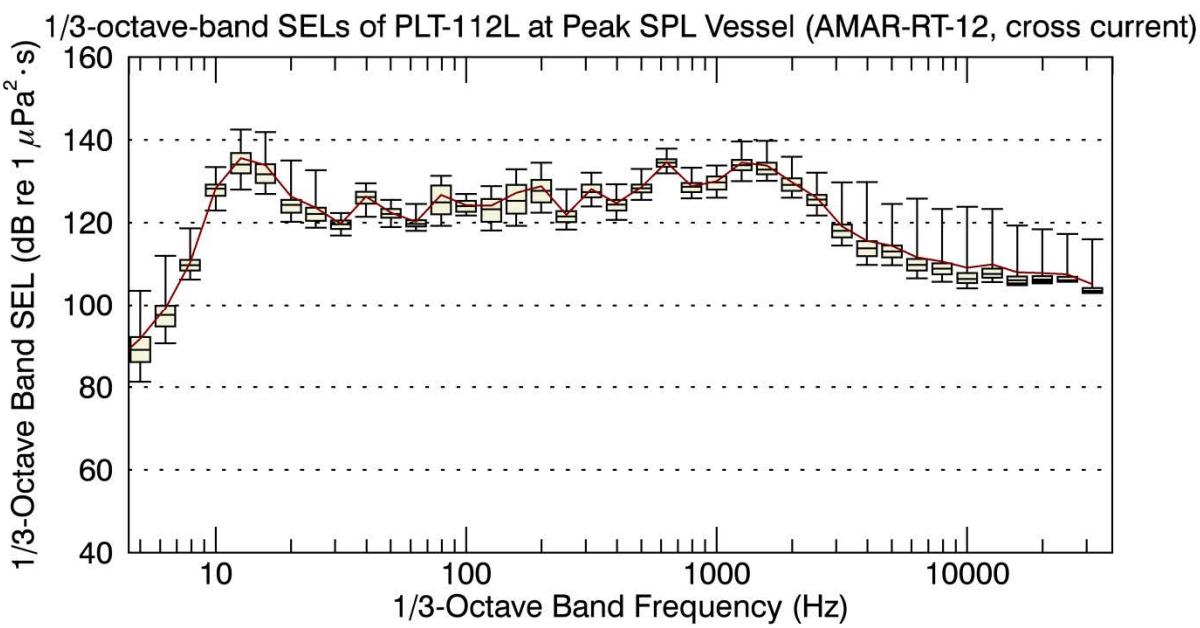


Figure 10. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112L measured 270 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels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

Table 13. Sound levels for the pile driving of Test Pile PLT-112L measured 270 ft from the pile at location Peak SPL Vessel using AMAR-RT-12.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	170.5	154.1	147
L_5	167.2	153.1	146.1
L_{25}	165.4	150.4	144.3
L_{50}	164.3	149.2	143.2
L_{75}	163.6	148.3	142.6
L_{95}	162.5	147.4	141.9
L_{mean}	164.8	149.9	143.6

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

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

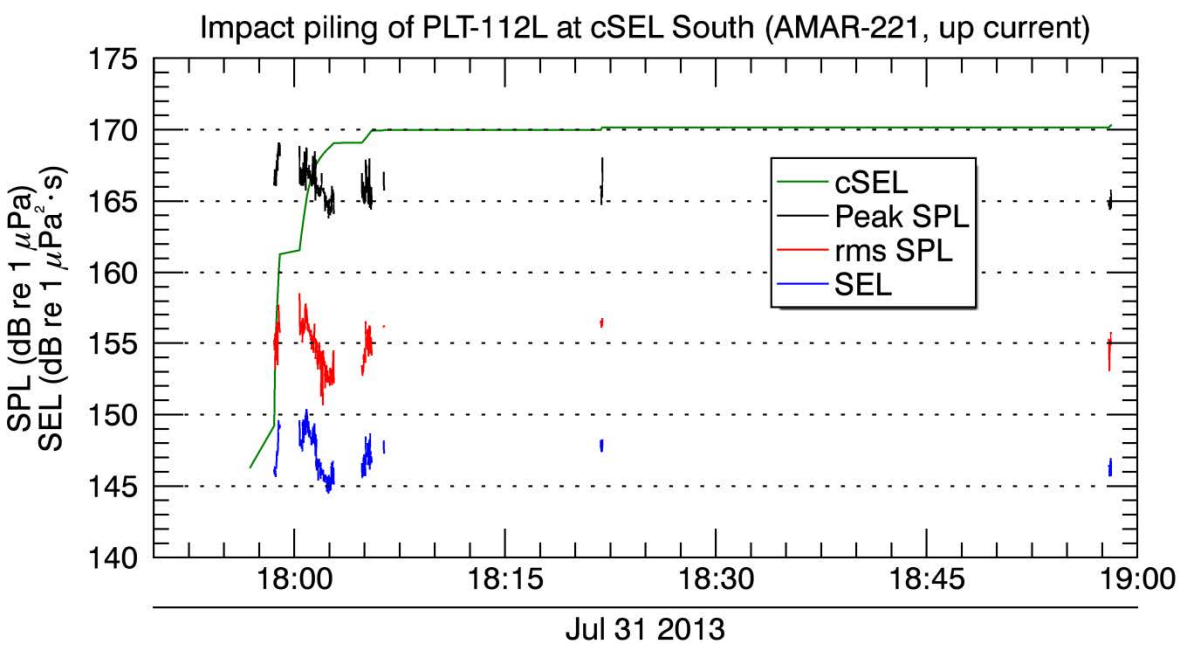


Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 556 ft from the pile at location cSEL South using AMAR-221.

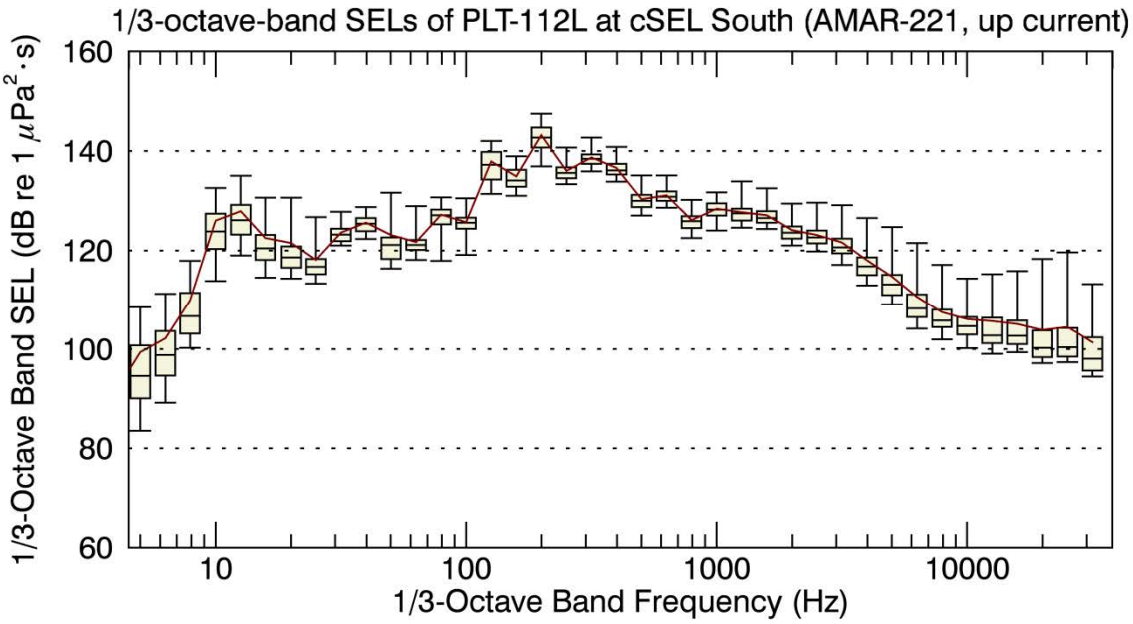


Figure 12. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112L measured 556 ft from the pile at location cSEL South using AMAR-221. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}).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

Table 14. Sound levels for the pile driving of Test Pile PLT-112L measured 556 ft from the pile at location cSEL South using AMAR-221.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa²s)
L_{max}	169.1	158.5	150.4
L_5	168.4	156.7	149.6
L_{25}	166.8	155.9	148.2
L_{50}	166	155	147
L_{75}	165.3	153.5	146
L_{95}	164.5	152.3	145.2
L_{mean}	166.3	155	147.4

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

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

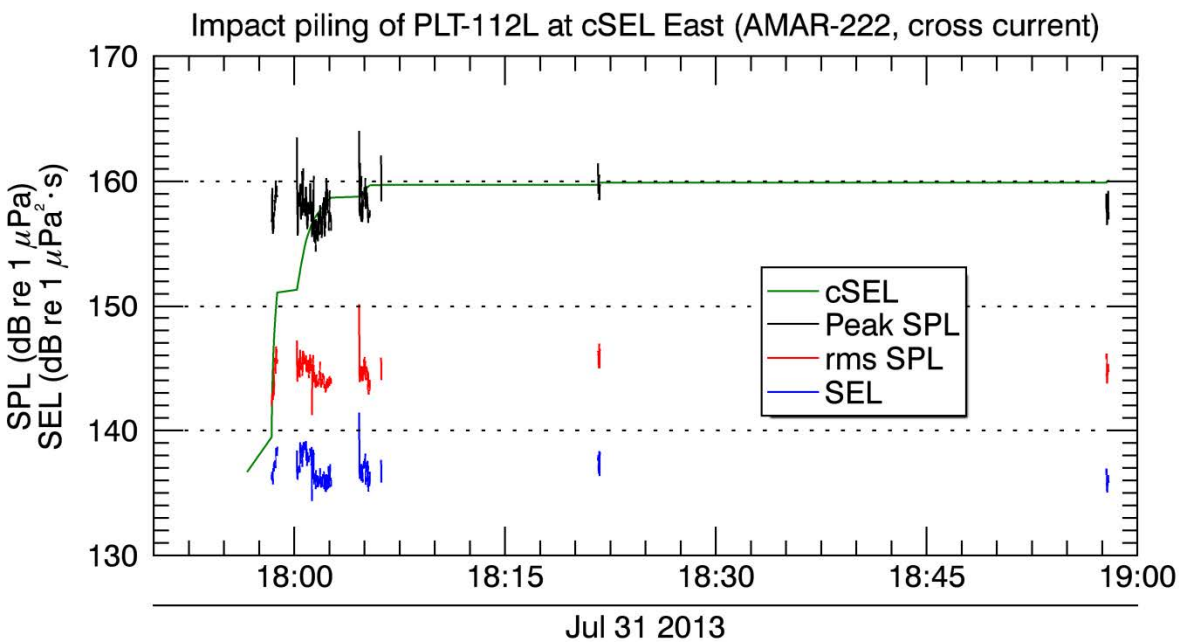


Figure 13. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 598 ft from the pile at location cSEL East using AMAR-222.

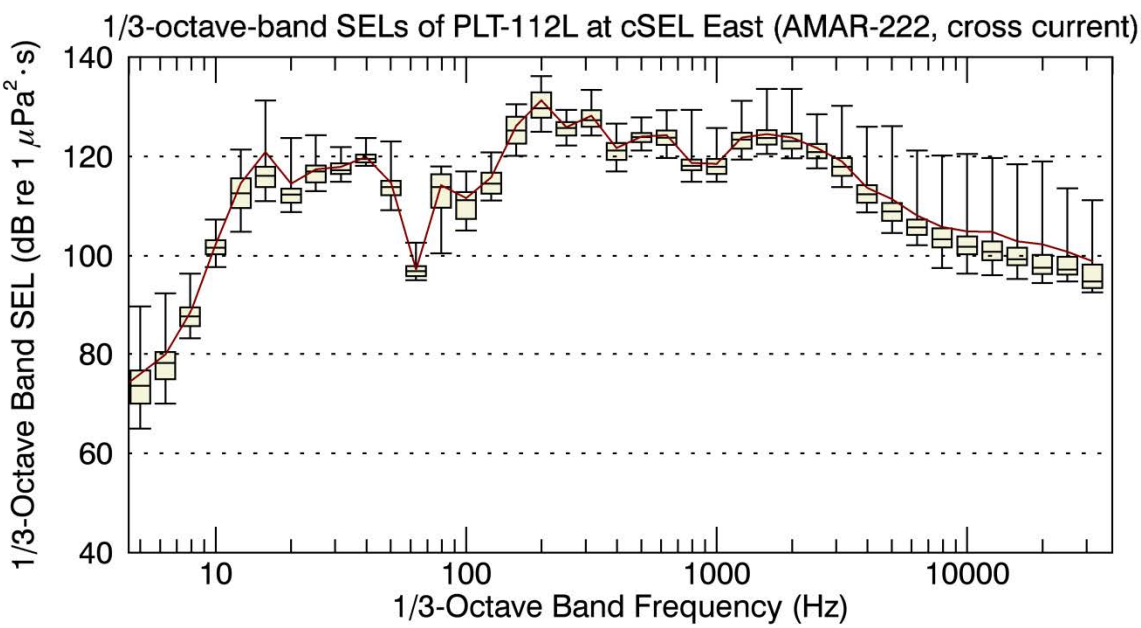


Figure 14. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112L measured 598 ft from the pile at location cSEL East using AMAR-222. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}).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

Table 15. Sound levels for the pile driving of Test Pile PLT-112L measured 598 ft from the pile at location cSEL East using AMAR-222.

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	164	150.1	141.4
L_5	160.3	146.2	138.7
L_{25}	158.6	145.3	137.6
L_{50}	157.8	144.6	136.7
L_{75}	156.9	143.9	136
L_{95}	155.7	142.9	135.3
L_{mean}	158.1	144.7	137

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

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

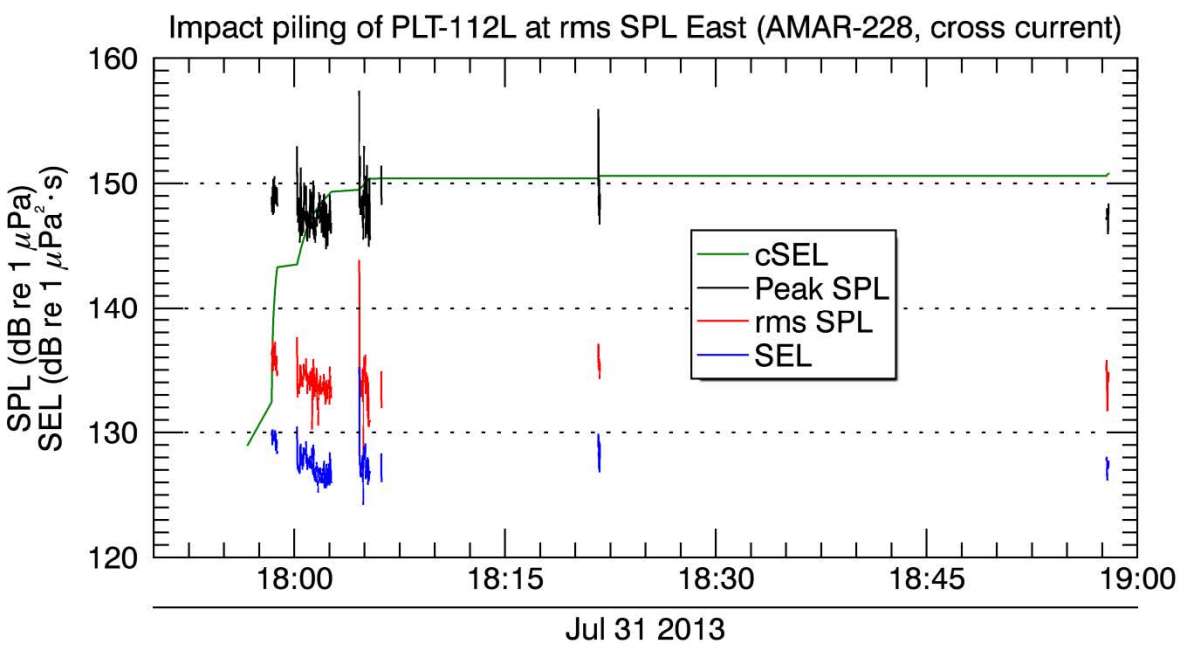


Figure 15. *Impact Pile Driving*: Peak SPL, rms SPL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112L measured 776 ft from the pile at location rms SPL East using AMAR-228.

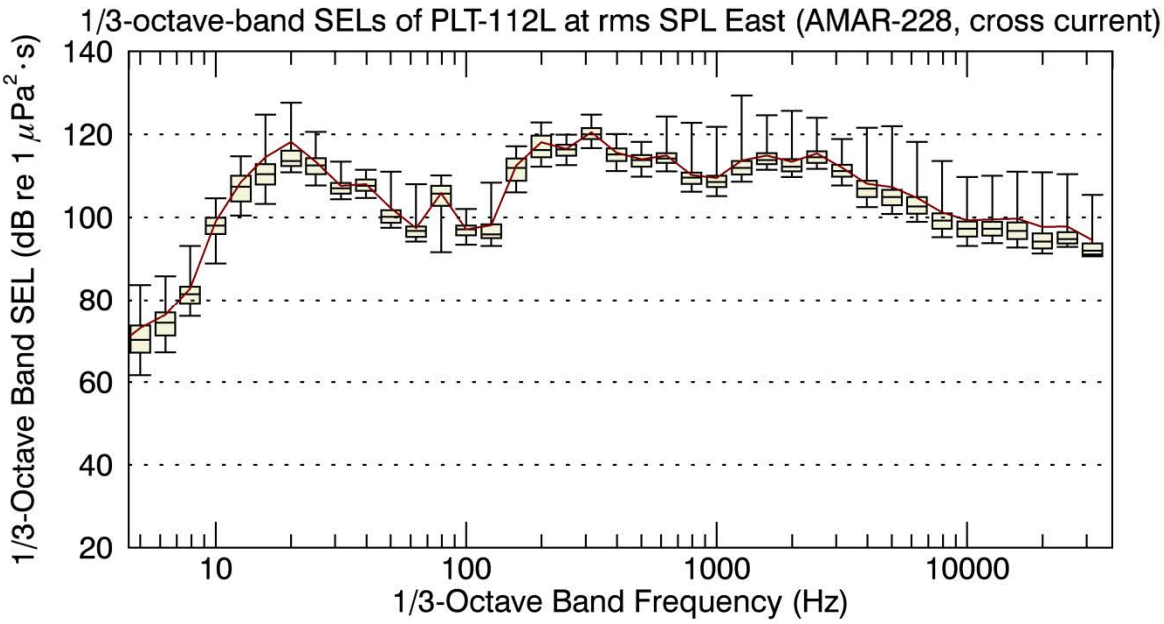


Figure 16. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112L measured 776 ft from the pile at location rms SPL East using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}).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

Table 16. Sound levels for the pile driving of Test Pile PLT-112L measured 776 ft from the pile at location rms SPL East using AMAR-228.Sound levels for the measurements at location rms SPL East during pile driving of PLT-112L (776 ft from pile PLT-112L, AMAR-228).

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa²s)
L_{max}	157.3	143.8	135.1
L_5	150.6	136.2	129.8
L_{25}	148.9	134.9	128.3
L_{50}	147.7	134.2	127.3
L_{75}	146.7	133.4	126.8
L_{95}	145.6	131.8	125.9
L_{mean}	148.4	134.5	127.8

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

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

Daily Memorandum for 03 August 2013

Submitted to:

[redacted]

Authors:

[redacted]

JASCO Applied Sciences

[redacted]

03 August 2013

P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-112 is a [redacted] pile driven at the site of the New NY Bridge on the east side of the navigation channel on 03 August 2013 (Table 1). Two real-time acoustic monitoring systems and three autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors LLC (TZC) to measure sound levels at ranges of 100–365 ft from the pile (Figure 1, Table 2). Piling driving occurred between 14:00–16:20 EDT, and full ebb tide occurred at 14:53 EDT.

The real-time systems were located 100 ft south of the pile and 170 east of the pile. The three autonomous systems surrounded the pile at the cSEL radius of approximately 300-ft in the north, south and east directions (actual ranges of 282, 365, and 238 ft)

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

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

Date:	03 August 2013
Pile-Driving Activity	
Test pile identifier:	PLT-112
Pile diameter:	[redacted]
Water depth	42 ft
Hammer type:	Impact (IHC S-800)
Total hammer strikes:	1089
Total penetration	179 ft
Net duration of pile driving (hh:mm:ss):	00:26:00
Maximum single strike energy:	569 thousand foot-pounds (kip-ft), (776 kJ)
Total energy transferred:	271,310 kip-ft (390 MJ)
Noise Attenuation System (NAS)	
Five-tier unconfined bubble curtain airflow rate:	900–2000 cubic feet per minute (cfm), 40–70 pounds per square inch (psi)
River conditions during piling:	Ebb tide, 1–2 knots (0.5–1 meters per second [m/s] depth dependent; Table 8, Figure 5)

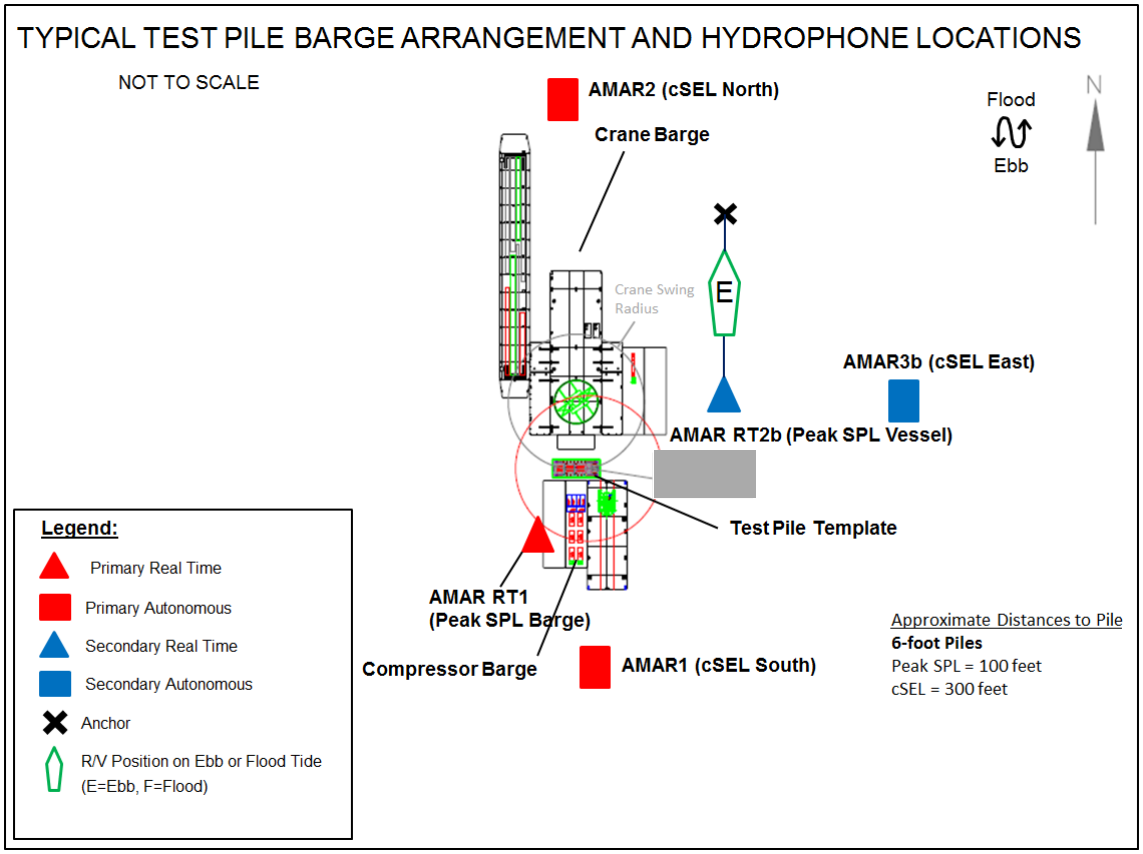


Figure 1. Plan view of pile and barge layout, 03 August 2013, PLT-112

Table 2. Summary of AMAR locations and measured sound levels. Detailed sound level plots are contained in Appendix A.

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

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

1.2. NMFS Physiological and Behavioral Thresholds

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

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was less than 6 ft, and did not exceed NMFS criteria of a diameter of 200 ft [redacted] The diameter of the 187 dB re 1 µPa^2·s cumulative sound exposure level (cSEL) isopleth was estimated to be 190 ft at the end of pile driving. Since cSEL increases as the number of strikes increases, the diameter of the 187 dB isopleth was smaller than 190 ft for most of the pile driving operation. No other pile driving occurred during this pile load test. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

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

Criteria	Estimated mean radius (ft)
206 dB re 1 µPa peak SPL	<3
187 dB re 1 µPa^2·s cSEL*	95*
150 dB re 1 µPa rms SPL (1 s integration time)	462

* At the end of pile driving

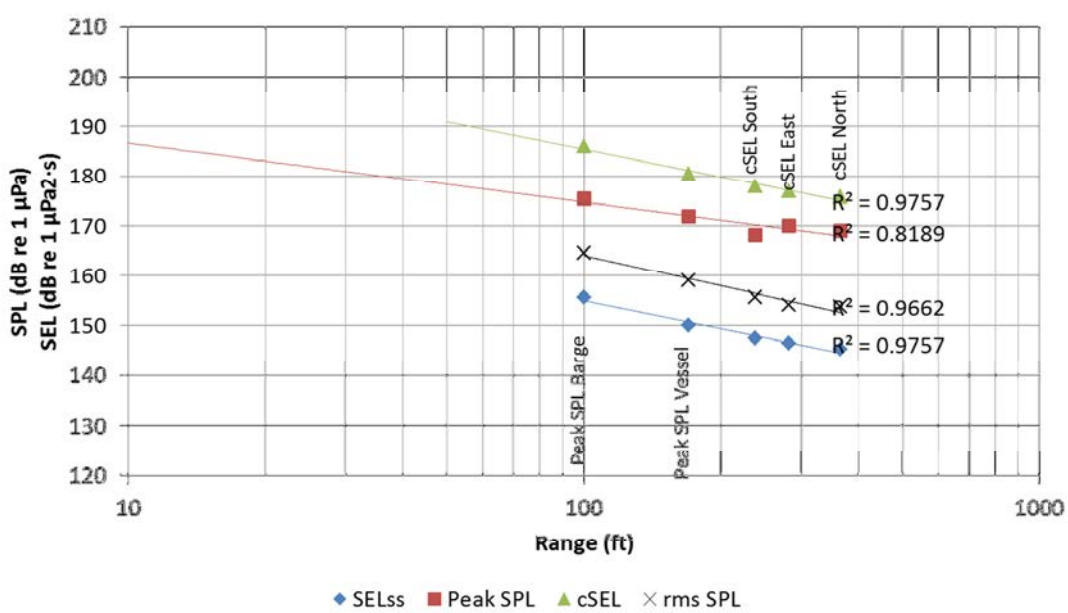


Figure 2. Regression based on mean values of the peak SPL, rms SPL, and single strike SELs from each recorder from pile driving of PLT-112, 03 August 2013. Single Strike SEL, Peak SPL, and rms SPL are instantaneous values. The cSEL represents total sound energy measured during the pile driving.

1.3. Observations

Sound levels appear to be negatively correlated with the NAS air flow (measured sound levels increase as air flow decreases) or positively correlated with the hammer energy. The effects of tidal state do not appear to affect the sound levels. To demonstrate this relationship Figure 3 presents the sound measurements at the location Peak SPL Barge annotated with the following NAS air pressure settings and hammer energy states:

- 70 psi and 100–150 kip-ft;
- 50 psi and 210 kip-ft; and
- 40 psi and 300–500 kip-ft.

Differences between the NAS settings/hammer energy states can be explored by subtracting the sound levels from the 70 psi measurements from the levels on the same recorder at the other settings (See Table 4). For example, peak SPL at cSEL North was 163 dB at 70 psi, and 171 dB at 40 psi, for a difference of 8 dB. There is a 5–9 dB difference in the peak SPL, 4–6 dB difference in the rms SPL, and 4–6 dB difference in the single-strike SELs at each recorder among the three NAS settings/hammer energy states(Table 4). The sound levels were higher when the NAS setting was lower; however, hammer energy and river current were higher during the measurements with lower NAS air flow. The distances to each NMFS threshold meet the NMFS and NYSDEC permit thresholds in all measurements states (Table 5).

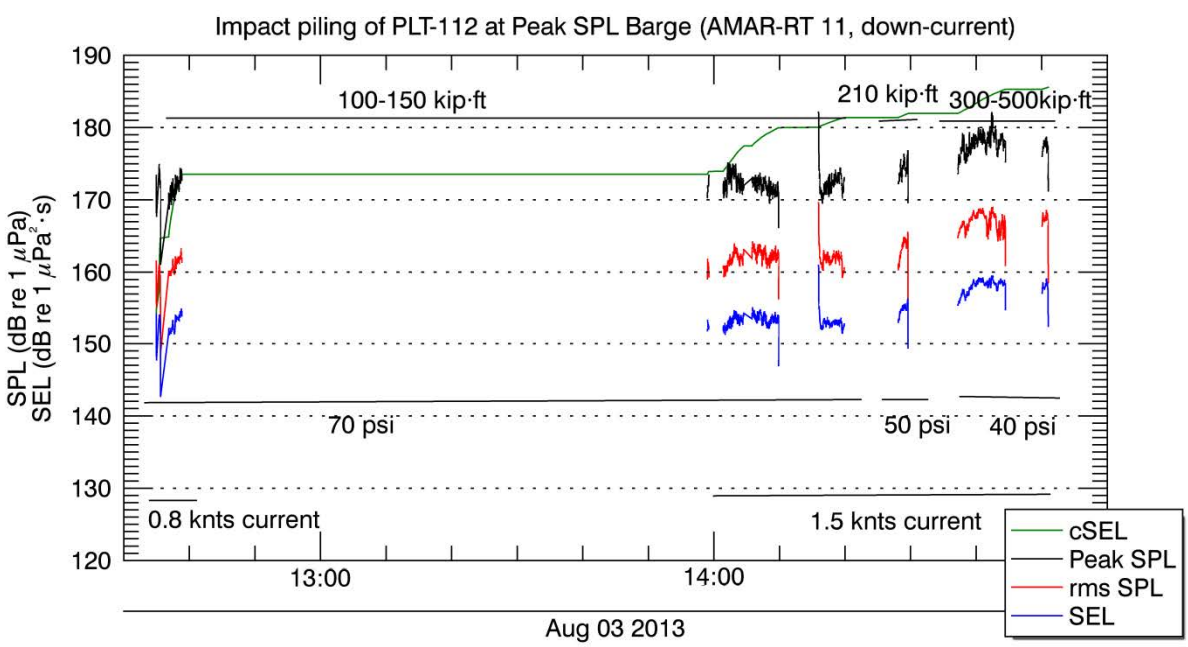


Figure 3. Measured sound levels versus time (EDT), hammer energy, noise-attenuation system pressure settings, and river current (knots). The measurements were made at location Peak SPL Barge, 100 ft down current from the pile.

Table 4. Median sound levels measured during each NAS air flow setting during installation of Test Pile PLT-112, 03 August 2013. Peak SPL and rms SPL units are dB re 1 µPa. SELss units are dB re 1 µPa^2·s. Effects of changing settings are found by subtracting the sound levels from the 70 psi measurements from the levels on the same recorder at the other settings. For example, peak SPL at cSEL North was 163 dB at 70 psi and 171 dB at 40 psi, for a difference of 8 dB.

Location	Distance to pile (ft)	70 psi, 100–150 kip-ft (650 strikes)			50 psi, 210 kip-ft (60 strikes)			40 psi, 300–500 kip-ft (340 strikes)		
		Peak SPL	rms SPL	SELss	Peak SPL	rms SPL	SELss	Peak SPL	rms SPL	SELss
Peak SPL Barge	100	172	162	153	174	163	155	177	167	158
Peak SPL Vessel	170	168	156	147	171	159	150	174	161	152
cSEL East	282	164	151	143	168	154	146	173	156	148
cSEL North	365	163	151	142	164	151	143	171	155	147
cSEL South	238	164	152	144	166	155	147	170	158	150

Table 5. Estimated isopleth radii for the NMFS physiological and behavioral thresholds as a function of NAS air pressure. The cSEL radius is estimated for all states as if there were 1089 strikes.

Criteria	Estimated Radius (ft)		
	70 psi 100–150 kip-ft	50 psi 210 kip-ft	40 psi 300–500 kip-ft
206 dB re 1 µPa peak SPL	<3	<3	<3
187 dB re 1 µPa^2·s cSEL	58	80	112
150 dB re 1 µPa rms SPL (1 s integration time)	387	441	610

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 6 provides activities for 03August 2013.

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

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

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

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Five-tier unconfined bubble curtain

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

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

2.2.2. Impact Hammering Log

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

Total number of strikes: 1089

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

Net piling duration (hh:mm:ss): 00:26:00

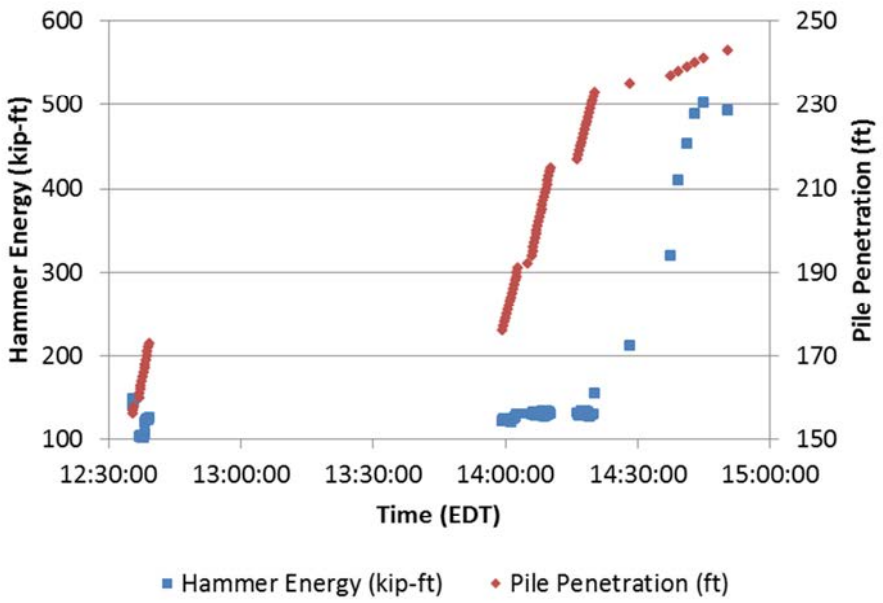


Figure 4.Hammer energy and pile penetration for the impact piling of PLT-112, 03 August 2013.

3. Weather and River Conditions

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

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

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

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

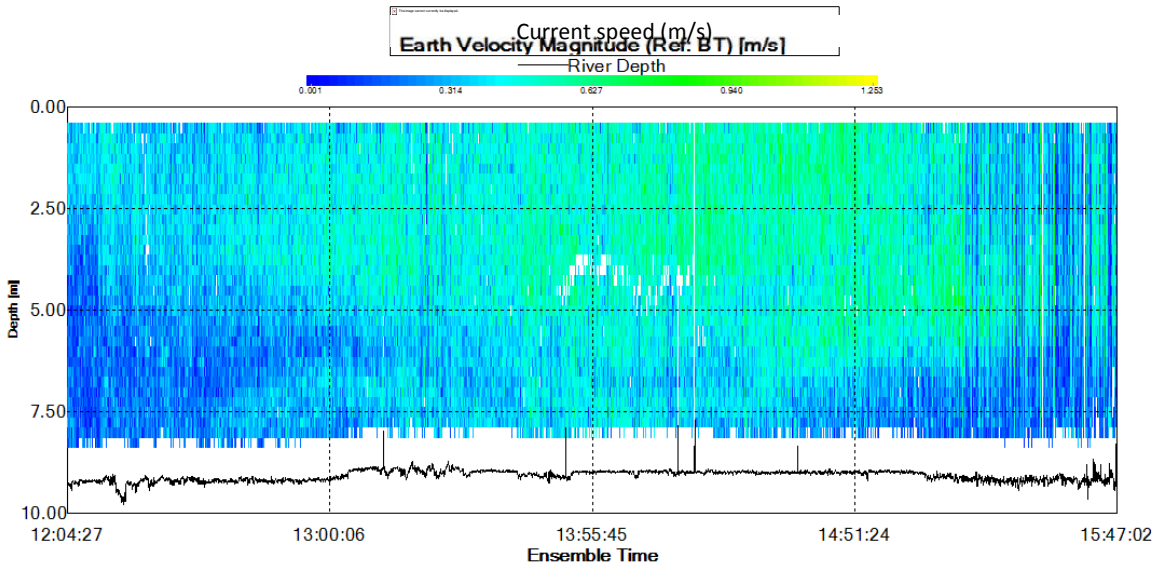


Figure 5. ADCP data from 03 August 2013 at the Peak SPL Vessel location, times are in EDT.

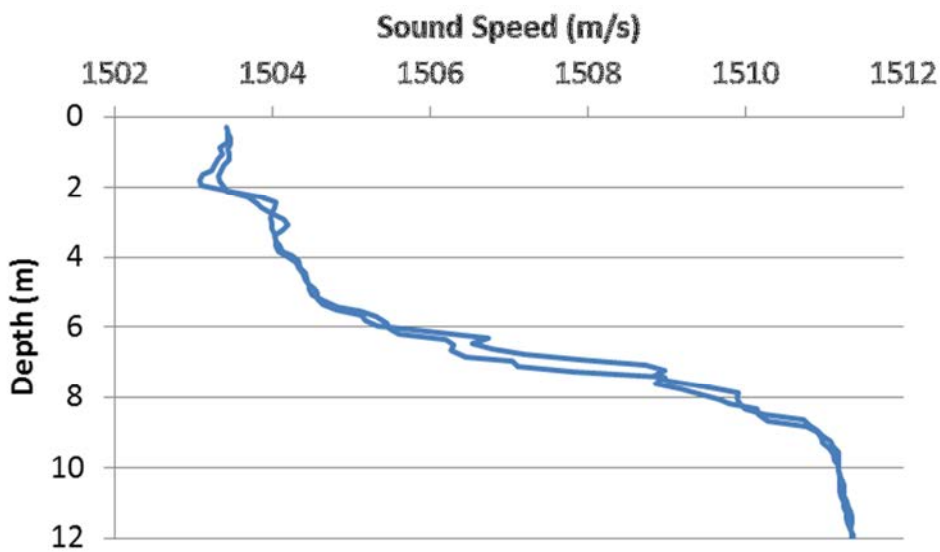


Figure 6. CTD Cast performed at 15:56 (EDT) from the Alpine vessel at location Peak SPL Vessel.

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

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

Table 9. AMAR-RT information for Test Pile PTL-112, 03 August 2013.

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

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

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

4.2. Autonomous Monitoring Equipment

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

Table 11. Autonomous recorder information for Test Pile PTL112, 03 August 2013.

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

Table 12. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations 03 August 2013.

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

Appendix A. Pile Driving Plots

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

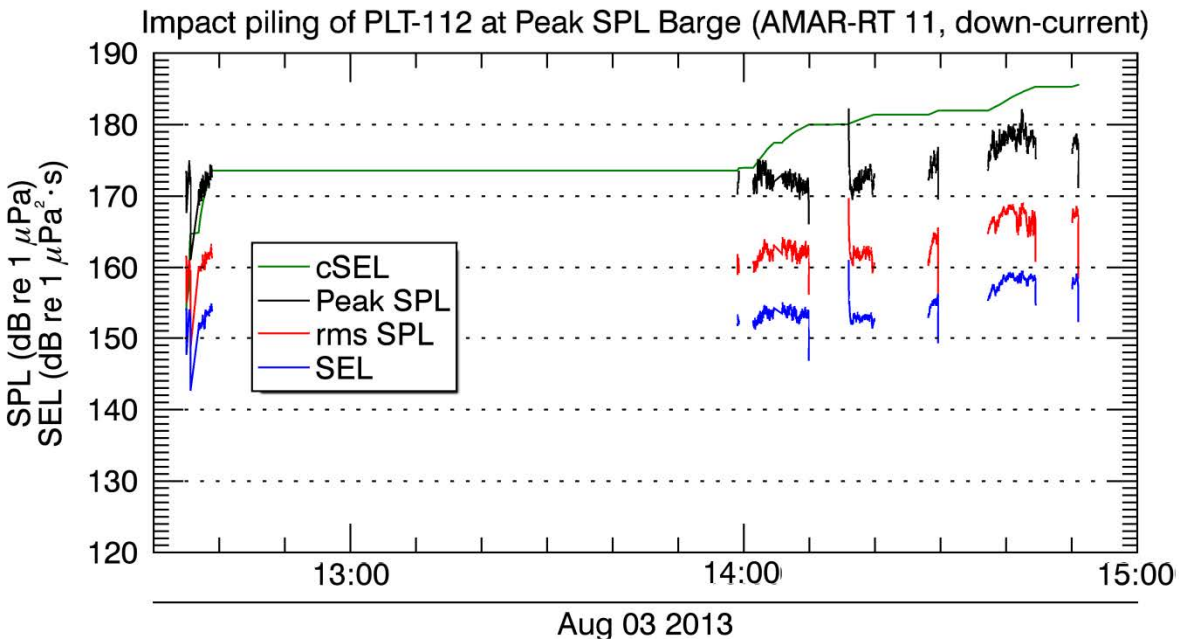


Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 100 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

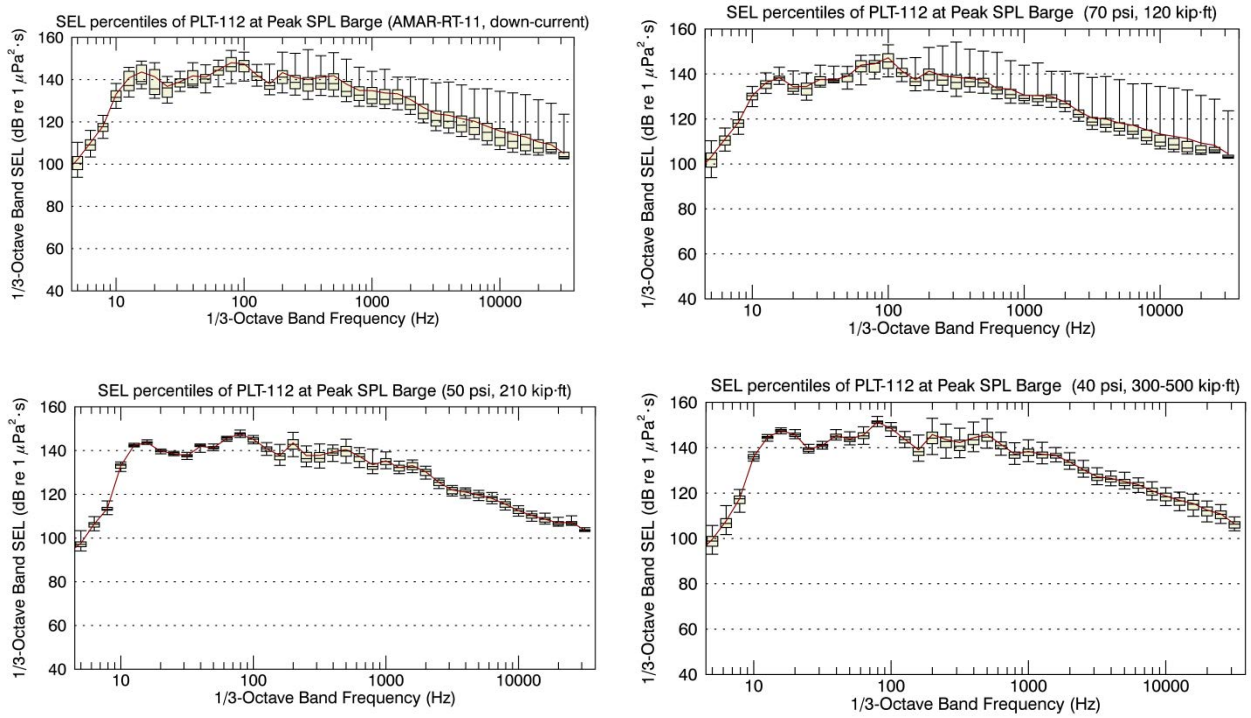


Figure 8. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112 measured 100 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}).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

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

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	182.1	169.6	160.9
L_5	179.1	168.3	158.9
L_{25}	177	166.3	157.7
L_{50}	173.2	162.8	153.9
L_{75}	171.9	161.8	152.9
L_{95}	170.7	160.5	152.1
L_{mean}	172.4	161.9	153.2

* The sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the *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 Vessel

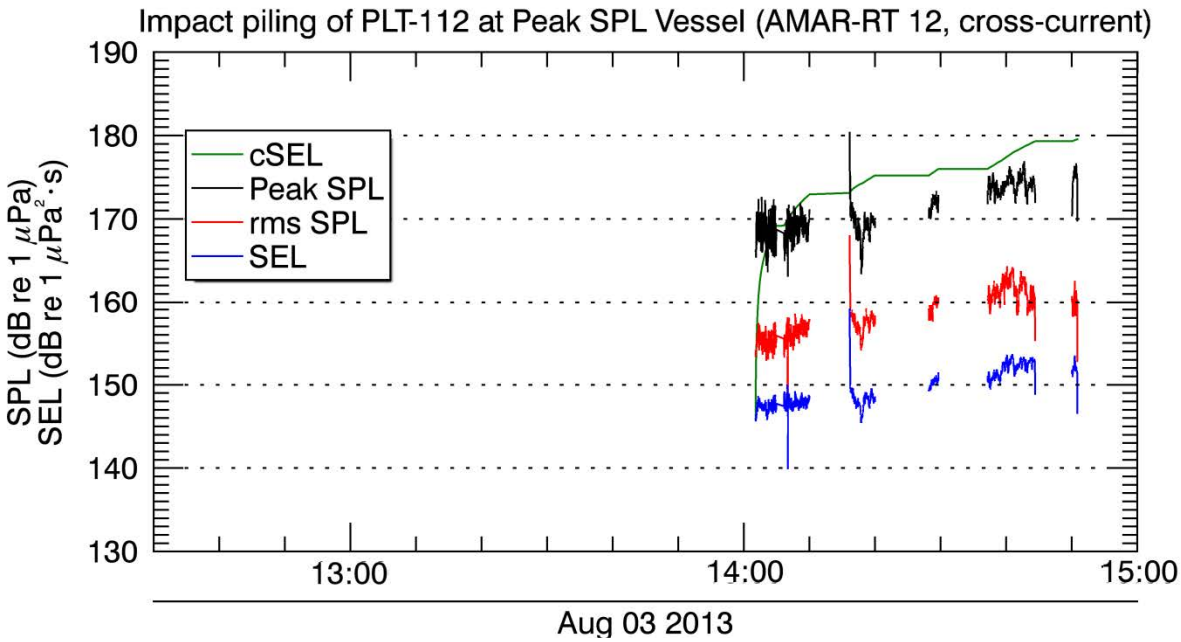


Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 170 ft from the pile at location Peak SPL Vessel using AMAR-RT-12.

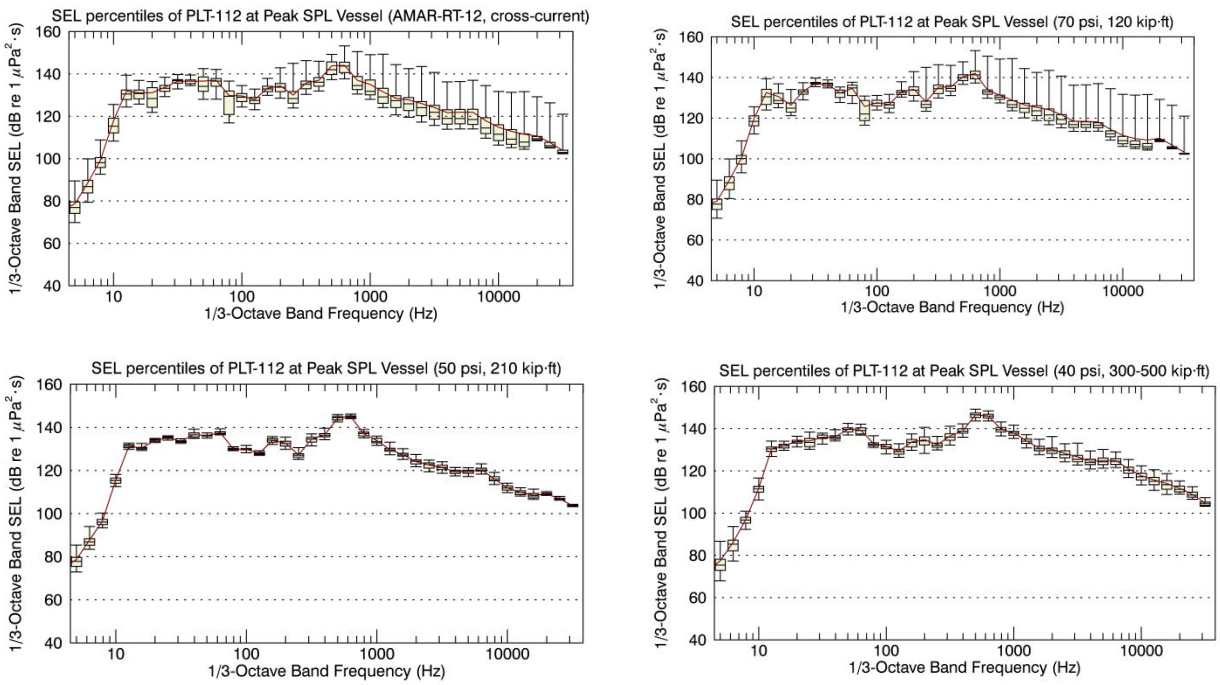


Figure 10. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112 measured 170 ft from the pile at location Peak SPL Vessel using AMAR-RT-12. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}).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

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

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	180.3	167.9	159
L_5	175.4	163	153
L_{25}	173.6	160.5	151.5
L_{50}	170.4	157.9	148.7
L_{75}	168.5	156.2	147.7
L_{95}	166.4	154.4	146.7
L_{mean}	169.1	156.7	148

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

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

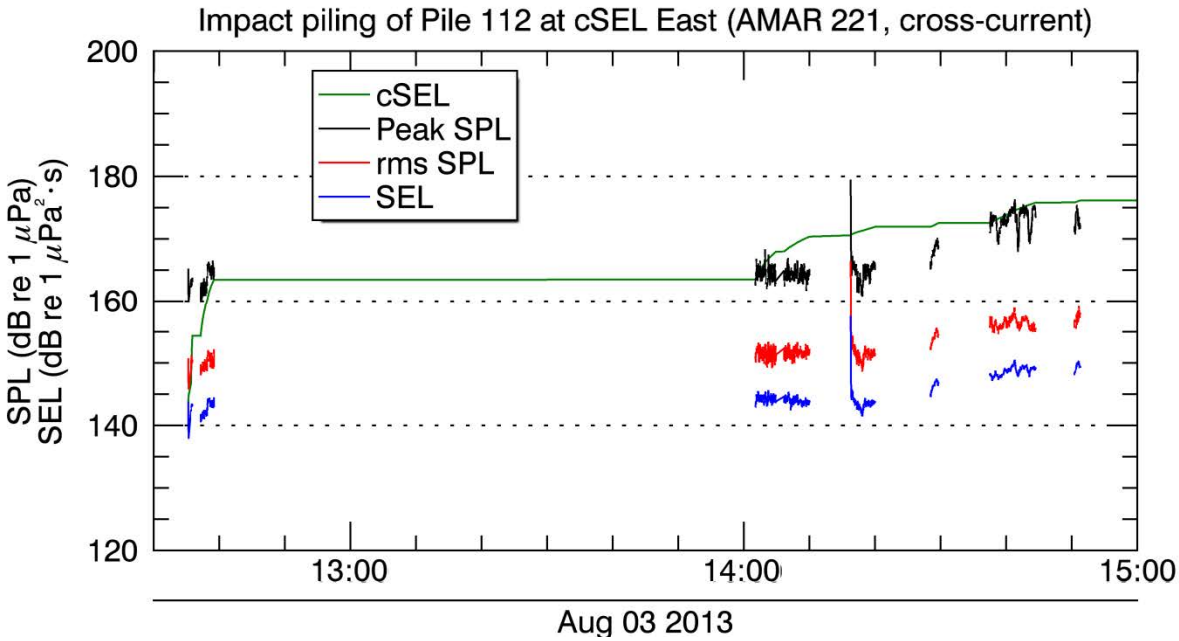


Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 282 ft from the pile at location cSEL East using AMAR-221.

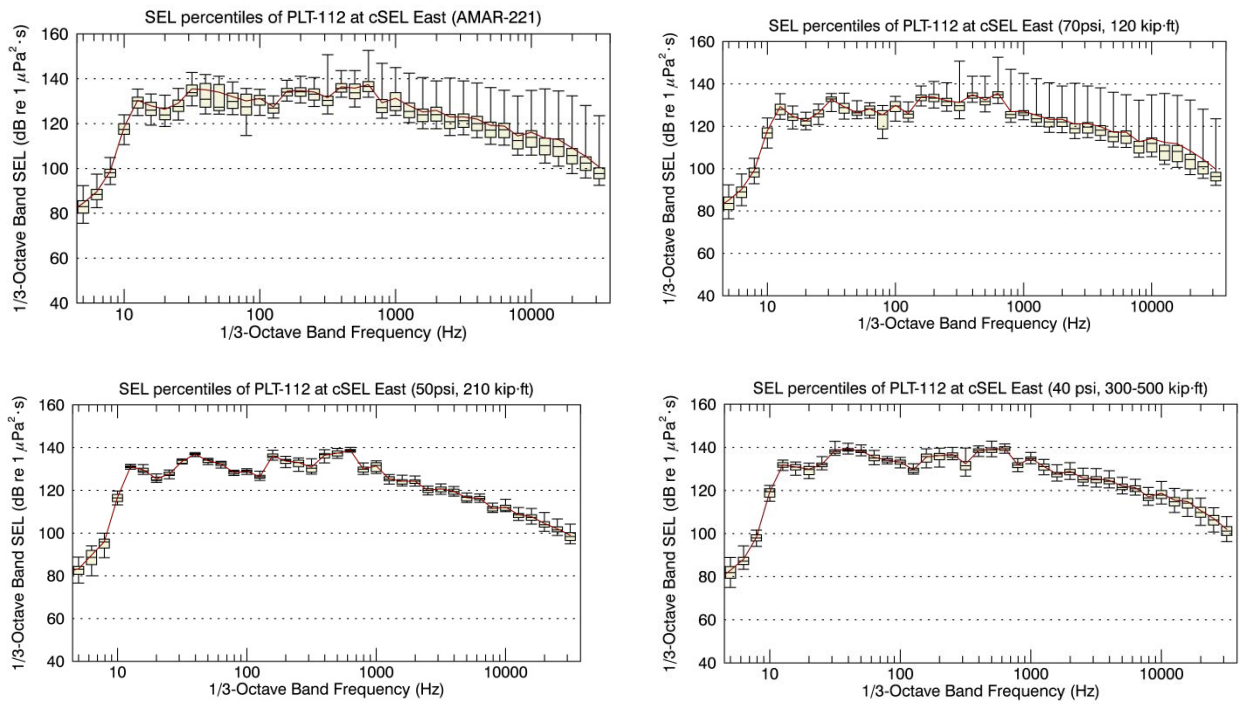


Figure 12. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112 measured 282 ft from the pile at location cSEL East using AMAR-221. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}).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

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

Sound level statistic*	peak SPL (dB re 1 μPa)	rms SPL (dB re 1 μPa)	Single strike SEL (dB re 1 μPa²s)
L_{max}	179.3	166.3	157.4
L_5	174.7	157.4	149.5
L_{25}	172.4	155.7	148.3
L_{50}	165.6	152.4	144.5
L_{75}	164.1	151.4	143.7
L_{95}	162.9	150.2	142.9
L_{mean}	164.7	151.6	143.9

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

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

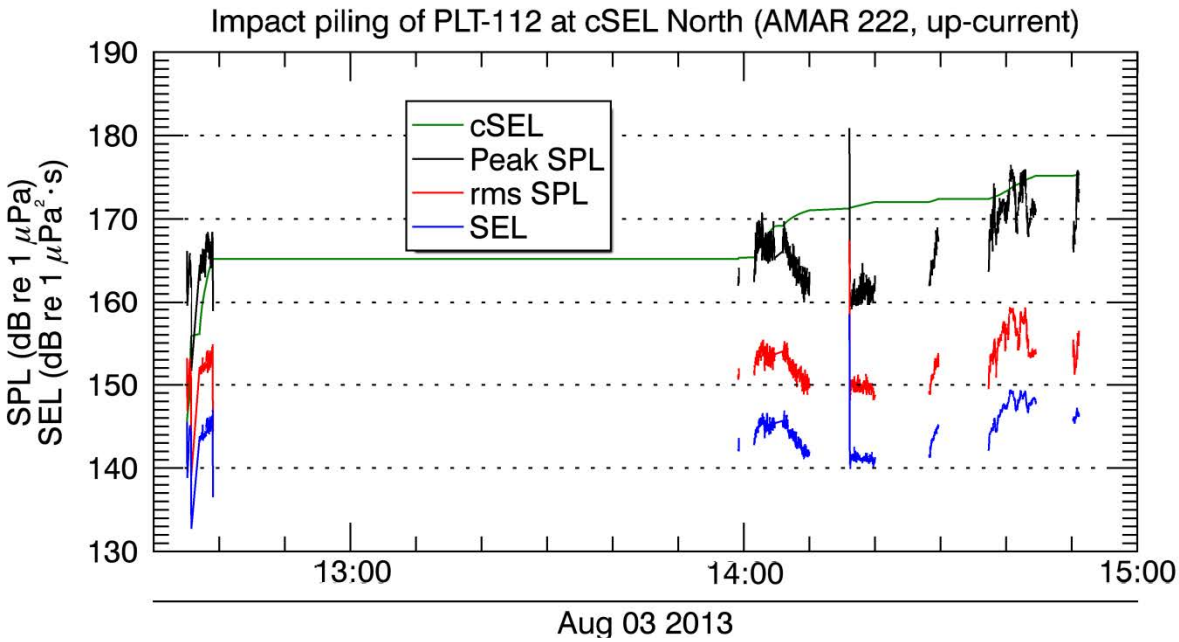


Figure 13. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 365 ft from the pile at location cSEL North using AMAR-222.Peak and rms sound pressure level (SPL) and cumulative sound exposure level (cSEL) versus time (EDT) measured at location cSEL North during pile driving at PLT-112 (365 ft from pile PLT-112, AMAR-222).

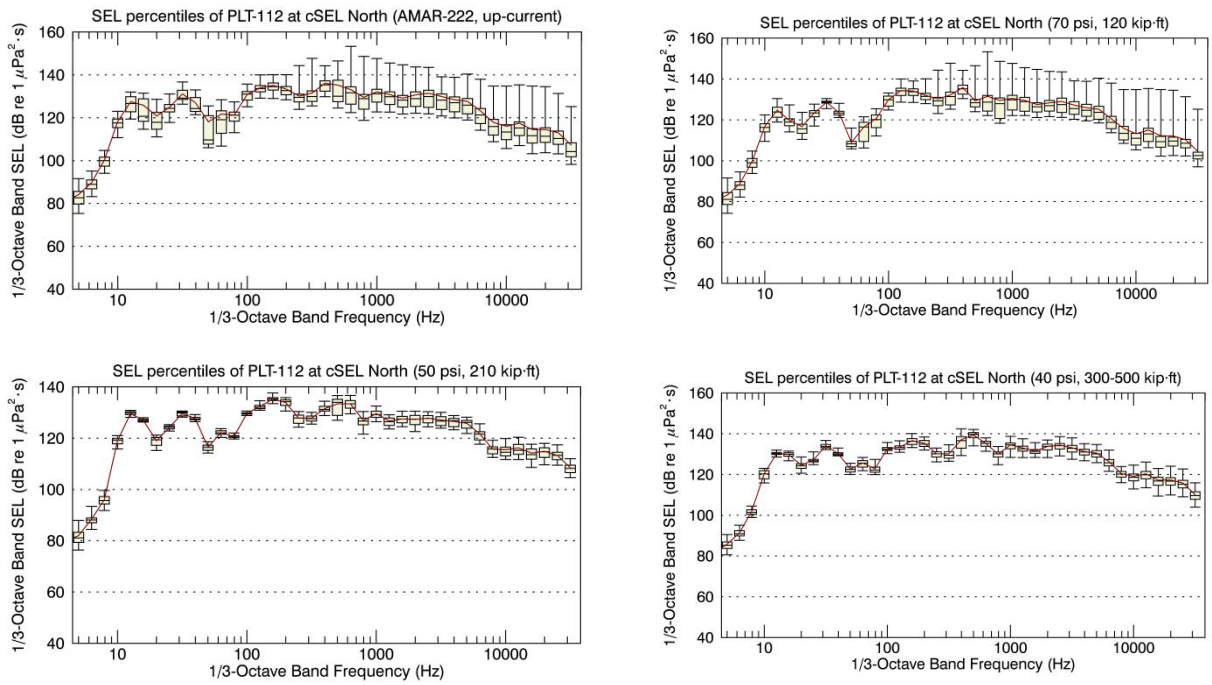


Figure 14. Distribution of /3-octave-band SELs for the pile driving of Test Pile PLT-112 measured 365 ft from the pile at location cSEL North using AMAR-222. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}).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

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

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	180.8	167.4	158.3
L_5	174.5	157.9	148.7
L_{25}	169.8	154.3	146.4
L_{50}	166.4	152.8	144.6
L_{75}	162.5	150.5	142
L_{95}	160.3	149.2	140.9
L_{mean}	165.2	152.2	143.9

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

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

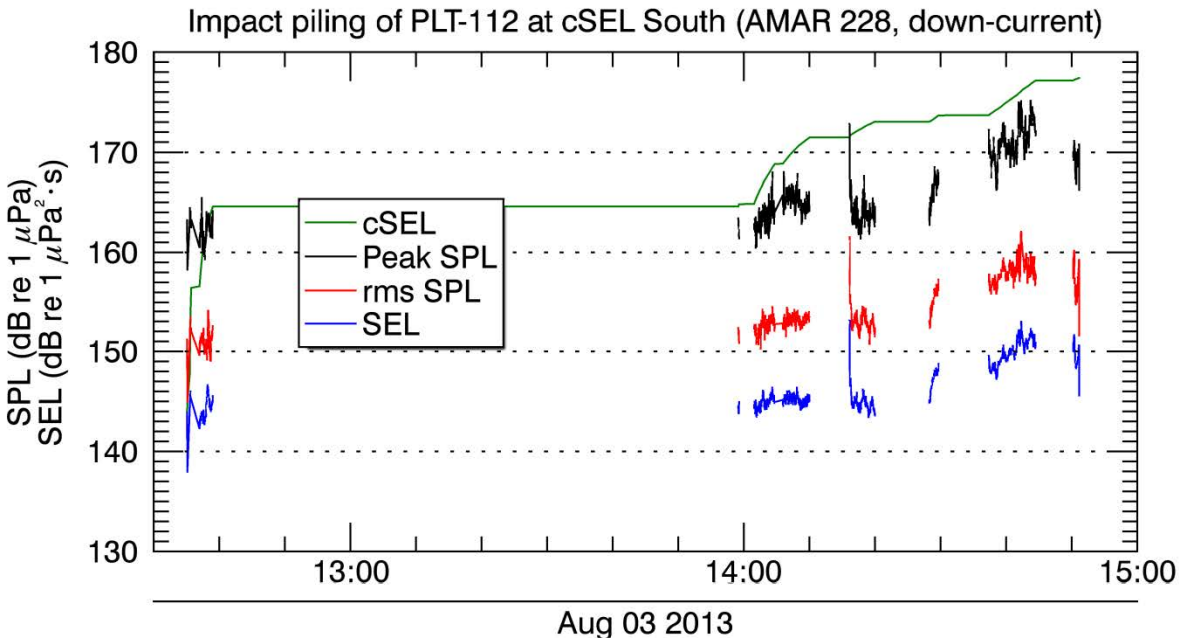


Figure 15. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112 measured 238 ft from the pile at location cSEL South using AMAR-228.

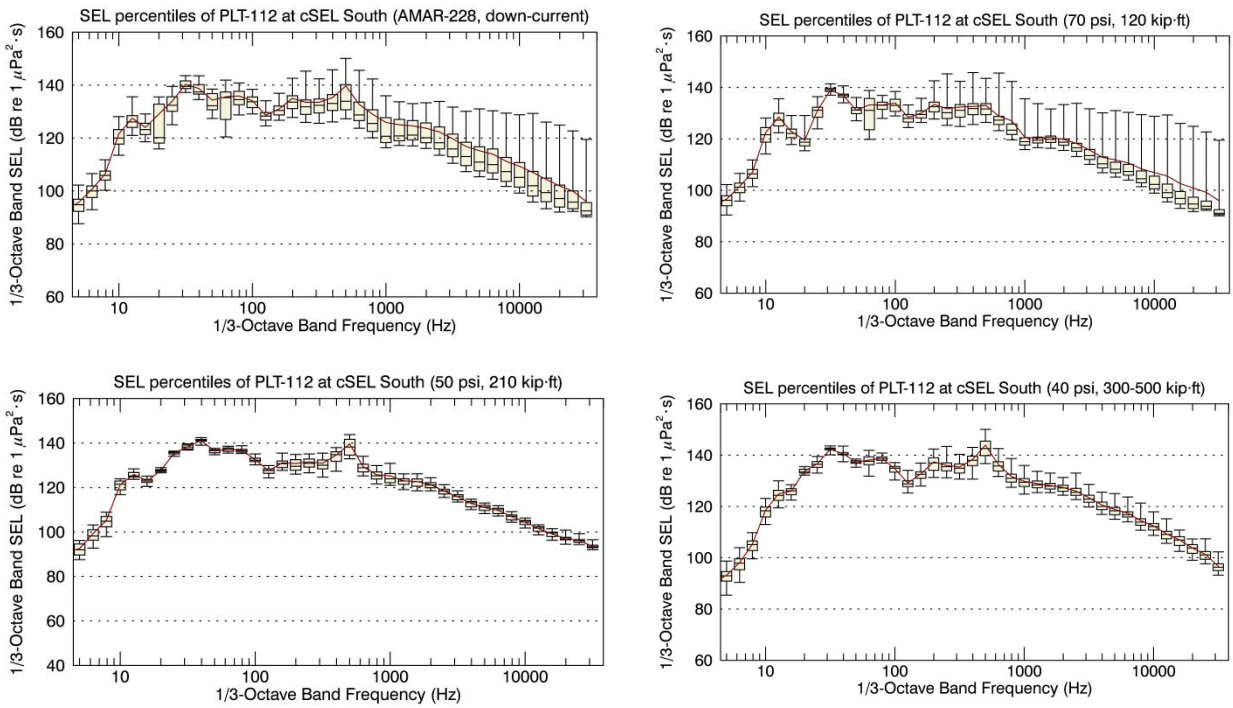


Figure 16. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112 measured 238 ft from the pile at location cSEL South using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}).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

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

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	175.2	162.1	153.2
L_5	172.9	159.3	151.5
L_{25}	169.9	157.2	149
L_{50}	165.4	153.6	145.5
L_{75}	163.9	152.7	144.9
L_{95}	162.3	151.8	144.1
L_{mean}	164.1	152.8	145

* 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 112RE Installation

Daily Memorandum for 16 September 2013

Submitted to:

[redacted]

Authors:

[redacted]

JASCO Applied Sciences

[redacted]

16 September 2013

P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-112RE is a [redacted] pile driven at the site of the New NY Bridge on the west side of the navigation channel on 16 September 2013 (Table 1). One real-time acoustic monitoring system and two autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors, LLC (TZC) to measure sound levels at ranges of 34.3–581 ft from the pile (Figure 1, Table 2). Pile driving occurred between 13:50–14:20 Eastern Daylight Time (EDT), and full ebb tide occurred at 13:58 EDT.

The real-time system was located north of the pile template, at a range of 34.3 ft from the pile. The two autonomous systems were aligned along a radial north of the pile at distances of 304 ft and 581 ft.

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

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

Date:	16 September 2013
Pile-Driving Activity	
Test pile identifier:	PLT-112RE
Pile diameter:	[redacted]
Water depth:	38 ft
Hammer type:	Impact (IHC S-800)
Total hammer strikes:	879
Total penetration:	237 ft
Net duration of pile driving (hh:mm:ss):	00:15:19
Maximum single strike energy:	168.0 thousand foot-pounds (kip-ft), (227 kJ)
Total energy transferred:	135,539 kip-ft (184 MJ)
Noise Attenuation System (NAS)	
Five-tier unconfined bubble curtain airflow rate:	1250–1400 cubic feet per minute (cfm), 70 pounds per square inch (psi)
River conditions during piling:	Ebb tide, 1.0-2.0 knots (0.5–1.0 meters per second [m/s] depth dependent see Table 7, and Figure 7)

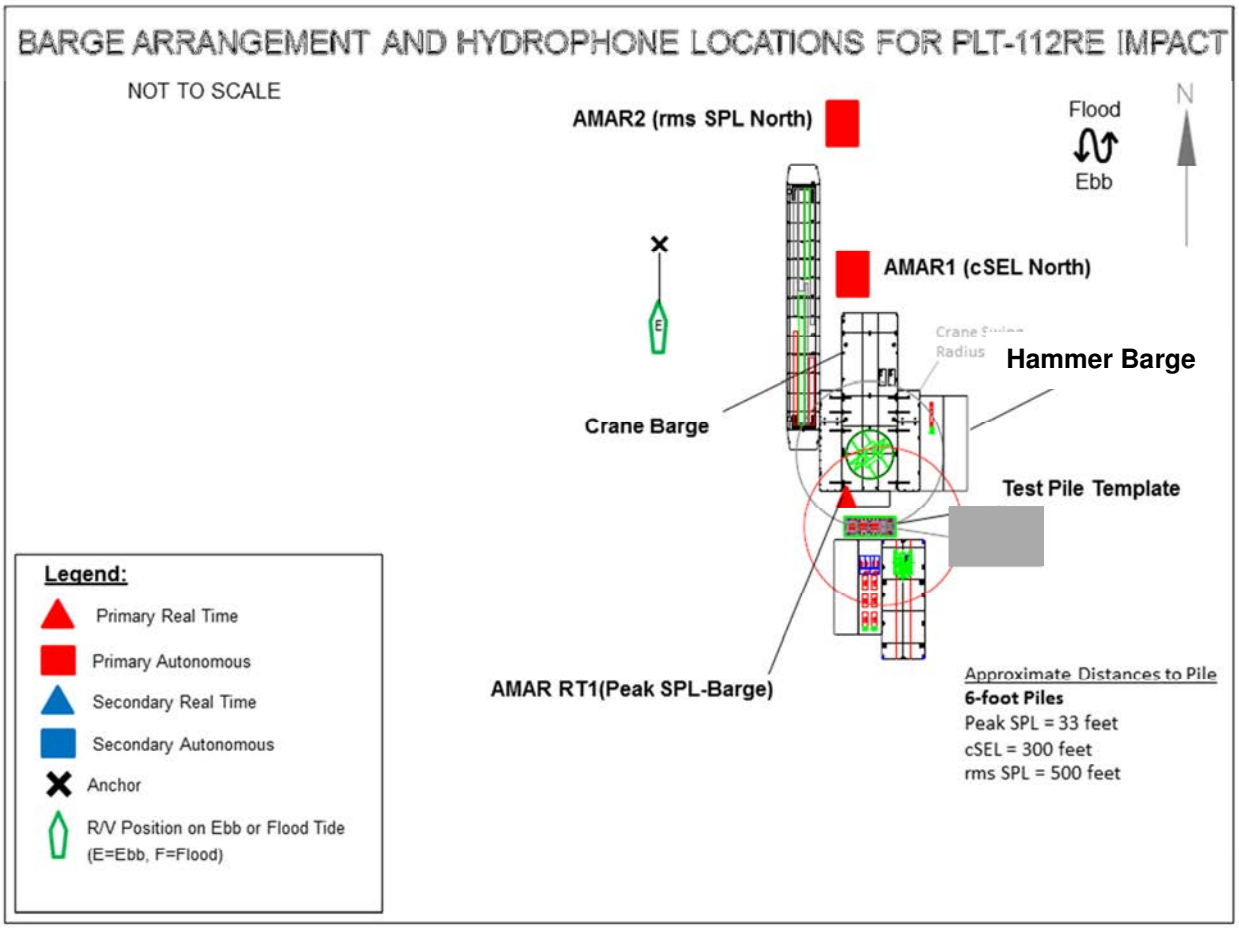


Figure 1. Plan view of pile and barge layout, 16 September 2013, Test Pile PLT-112RE.

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

Location	Recorder ID	Distance to pile (ft)	Water depth (ft)	Max peak SPL (dB re 1 µPa)	cSEL (dB re 1 µPa^{2}s)*
Peak SPL Barge (up current)	AMAR-RT-11	34.3	38	202	196.9
cSEL North (up current)	AMAR-175	304	36	183.9	174.5
rms SPL North (up current)	AMAR-228	581	36	171	168.4

* 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 single strike SELss from each recorder (Table 3 and Figure 2).

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was approximately 16 ft, and did not exceed NMFS criteria of a diameter of 200 ft for [redacted] piles. The diameter of the 187 dB re 1 µPa^2•s cumulative sound exposure level (cSEL) isopleth was estimated to be 184 ft at the end of pile driving. Since cSEL increases as the number of strikes increases, the diameter of the 187 dB isopleth was smaller than 184 ft for most of the pile driving operation. No other pile driving occurred during this pile load test. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

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

Criteria	Estimated mean radius (ft)
206 dB re 1 µPa peak SPL	8.0
187 dB re 1 µPa^2·s cSEL*	92
150 dB re 1 µPa rms SPL (1 s integration time)	392

* At the end of pile driving

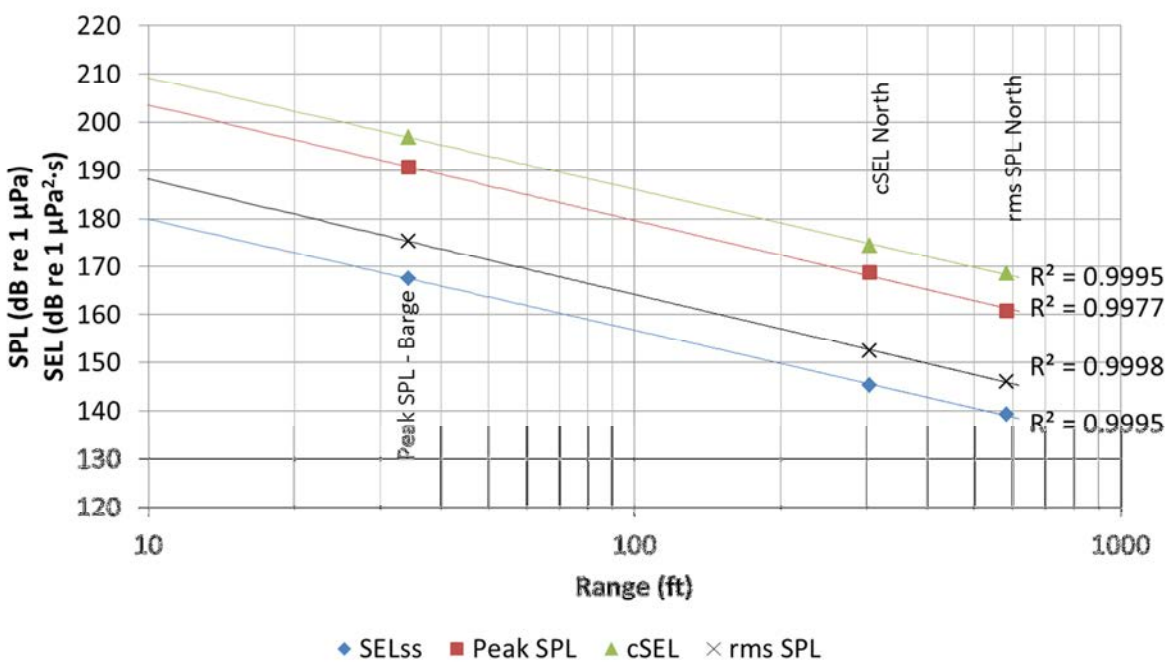


Figure 2. Regression based on mean values of the peak SPL, rms SPL, and single strike SELs from each recorder from pile driving of Test Pile PLT-112RE, 16 September 2013. SEL_{ss}, peak SPL, and rms SPL are the mean instantaneous values. The cSEL represents the total sound energy measured during the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

1.3. Observations

Acoustic measurements at PLT-112RE were made along a radial up current from the pile during full ebb current in deep water. Currents were measured by the ADCP to be in excess of 2 knots at the surface and 1.0 knots at the river bottom (Figure 7). The NAS system was operated at 70 psi (1250-1400 cfm) during the piling of PLT-112RE (Table 6). The hammer was operated at 150+/-10 kip-ft for most of the pile (Figure 3, Figure 6). The pile penetrated the substrate at a continuous rate from 13:52–14:05, then hit refusal (Figure 3, Figure 6). Over this period of approximately 13 minutes (13:52-14:05), occurring before refusal impact driving, peak SPL, rms SPL and SELss decreased at each recorder by 6-15 dB. Peak SPL decreased by 15 dB at location Peak SPL Barge, 9 dB at location cSEL North, and 8 dB at location rms SPL North (Figure 9, Figure 11, Figure 13). rms SPL decreased by 12, 12, and 9 dB while SELss decreased by 11, 8, and 6 dB respectively (Figure 9, Figure 11, Figure 13). Piling continued sporadically from 14:05 to about 14:23 at the same hammer energies however the only penetrated three more feet (Figure 3).

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

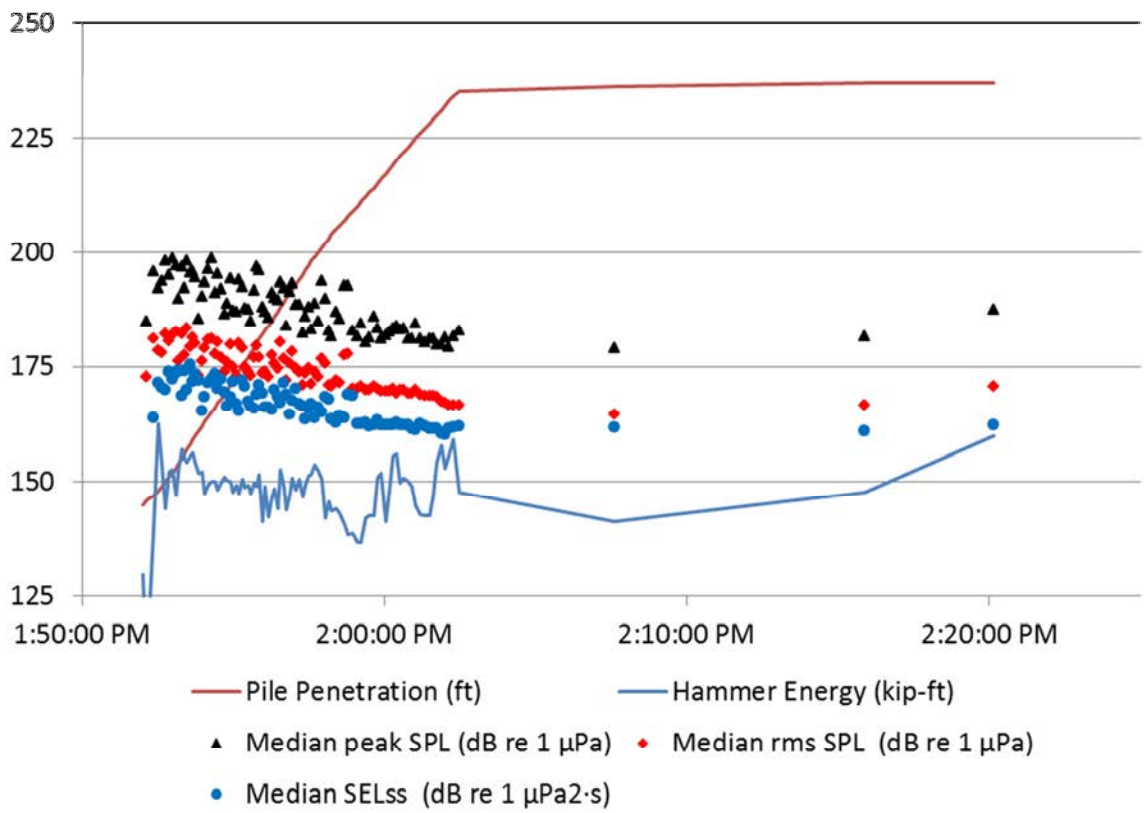


Figure 3. Median measured peak SPL, rms SPL and single strike SEL for each foot of penetration of PLT-112RE, compared to the pile penetration (ft) and the median hammer energy (kip-ft).

The sound level reductions from 13:52-14:05 were associated with decreases in energy above 200 Hz (Figure 4). Each panel in Figure 4 shows the distribution of 1/3-octave-band SELss from each recorder. To illustrate the effect of decreasing energy above 200 Hz the distributions from two-minutes at the beginning of pile driving is shown in the top row for contrast with the two-minute before refusal from 14:03-14:05. Recall that over the period of 13:52-14:05 SELss decreased by 11, 8, and 6 dB respectively at Peak SPL Barge, cSEL North, and rms SPL North. Note the SELss level in the 630 Hz band for the Peak SPL Barge location. At 13:52-13:54 the levels reach 170 dB re 1 $\mu Pa^2 \cdot s$. At 14:03-14:05 they do not exceed 145 dB. Conversely the levels at 63 Hz are virtually unchanged. This pattern is repeated for most of the 1/3-octave-bands above 200 Hz and for all three recorders

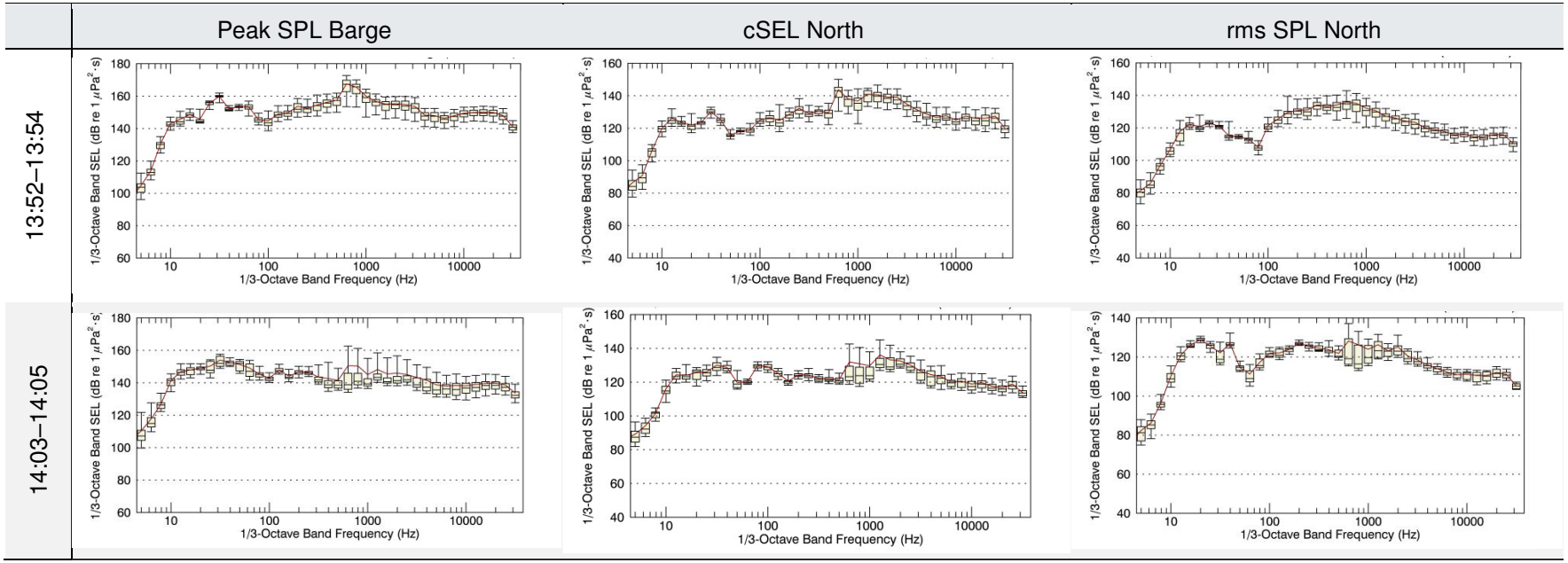


Figure 4. Reduction in sound in energy at frequencies above 200 Hz during the pile driving at PLT-112RE. Each figure shows the distribution of 1/3-octave SELss from each recorder. To illustrate the effects the top row shows a two minute time window from the beginning of pile driving, and the bottom row shows a two minute window at 14:03-14:05. Note the SEL level in the 630 Hz band for the Peak SPL Barge location. At 13:52-13:54 the levels reach 170 dB re 1 μPa^2·s. . At 14:03-14:05 they do not exceed 145 dB. Conversely the levels at 63 Hz are virtually unchanged. This pattern is repeated for most of the 1/3-octave-bands above 200 Hz and for all recorders. Left-hand column: Measurements from location Peak SPL Barge (34.3 ft from the pile). Middle column: measurements from location cSEL North (304 ft from the pile). Right-hand column: Measurements from location rms SPL North (581 ft from the pile). Top row: First 2.5 min of piling (13:52–13:54). Bottom row: Last 2 min of piling (14:03–14:05). 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}).

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

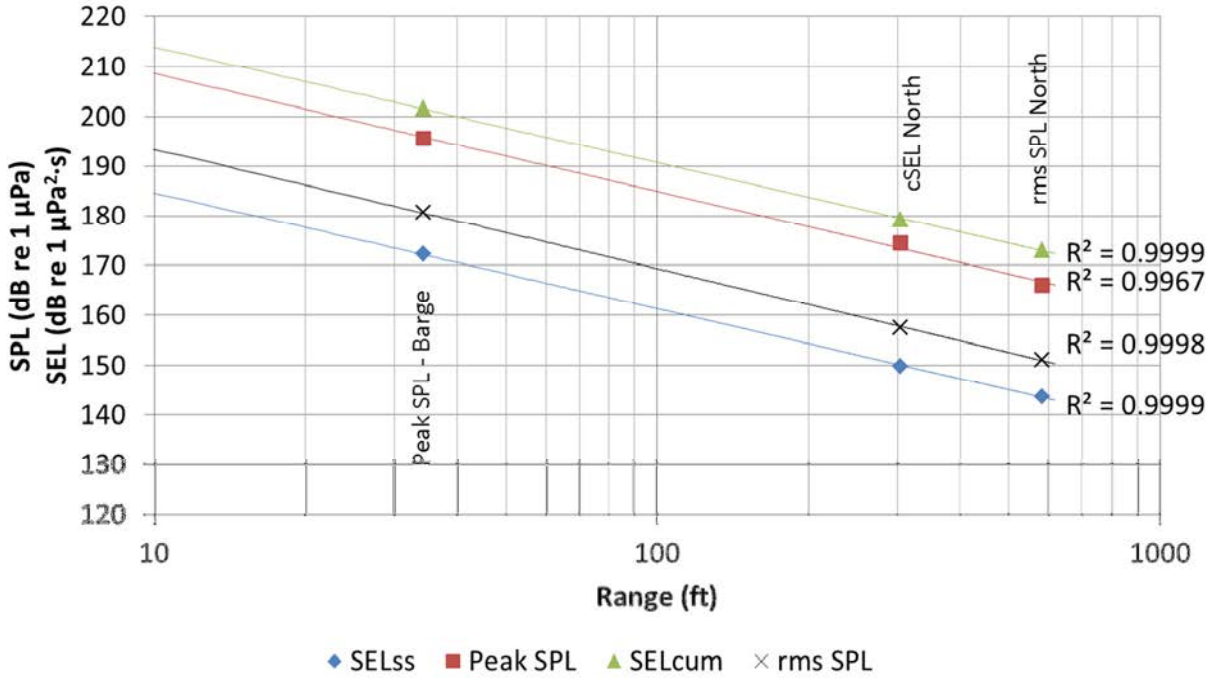


Figure 5. Regression based on mean values of the peak SPL, rms SPL, and single strike SELs from each recorder from pile driving of Test Pile PLT-112RE over the time range of 13:52-13:54 16 September 2013. SEL_{ss}, peak SPL, and rms SPL are the mean instantaneous values. The cSEL represents the total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

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

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

* At the end of pile driving assuming 879 strikes.

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 5 provides activities for 16 September 2013.

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

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

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Five-tier unconfined bubble curtain

NAS Settings: 1250–1400 cfm, 70 psi

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

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

2.2.2. Impact Hammering Log

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

Total number of strikes: 879

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

Net piling duration (hh:mm:ss): 00:15:19

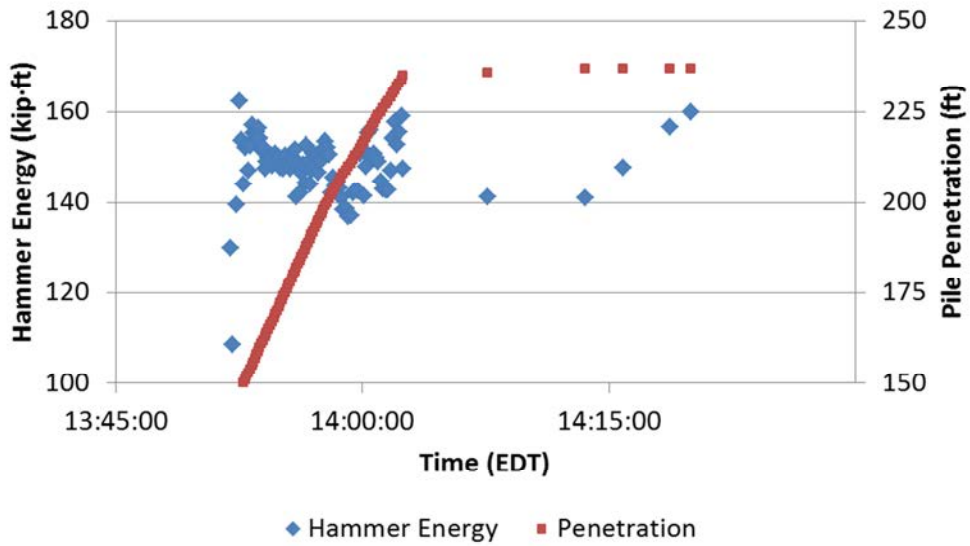


Figure 6.Hammer energy (kip-ft) and pile penetration (ft) during piling of PLT-112RE, 16 September 2013.

3. Weather and River Conditions

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

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

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

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

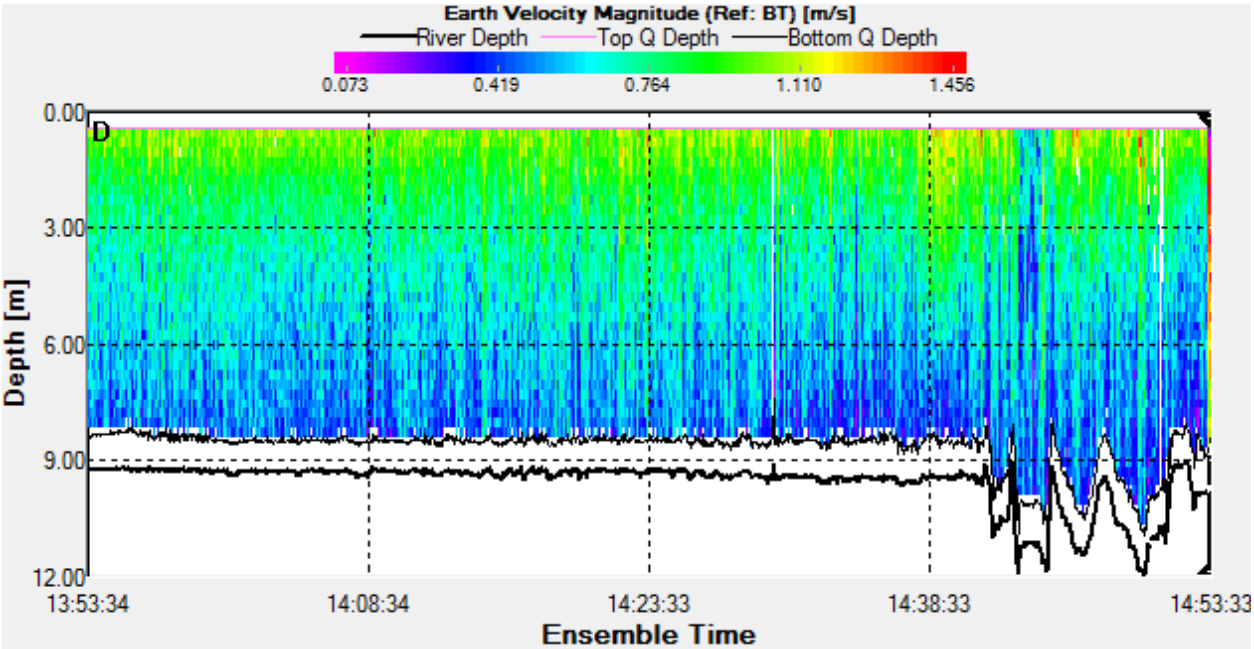


Figure 7. Current data measured by ADCP on 16 September 2013 from the Alpine vessel, located 581 ft north of the pile (41.07417 N, 73.91453 W), times are in EDT.

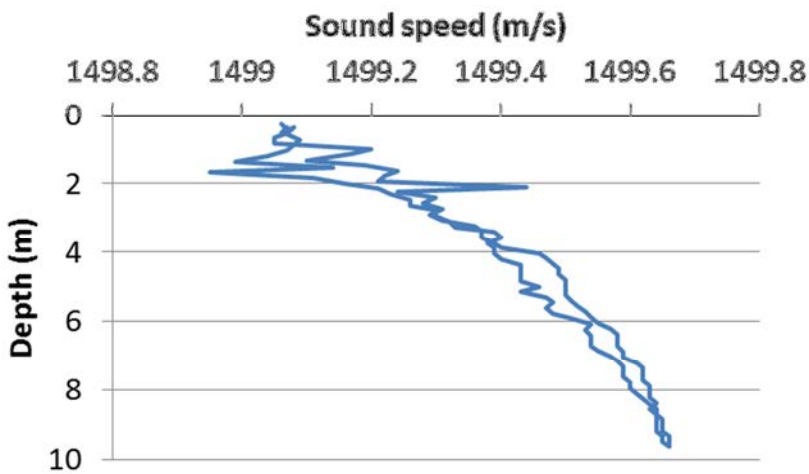


Figure 8. CTD cast performed at 13:56 EDT from the Alpine vessel at location rms SPL North.

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

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

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

Table 8. AMAR-RT information for Test Pile PTL-112RE, 16 September 2013.

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

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

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

4.2. Autonomous Monitoring Equipment

Table 10 provides information about the autonomous monitoring equipment used on 16 September 2013.

Table 11 provides the locations of the autonomous recorders.

Table 10. AMAR information for Test Pile PTL-112RE, 16 16September 2013.

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

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

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

Appendix A. Pile Driving Plots

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

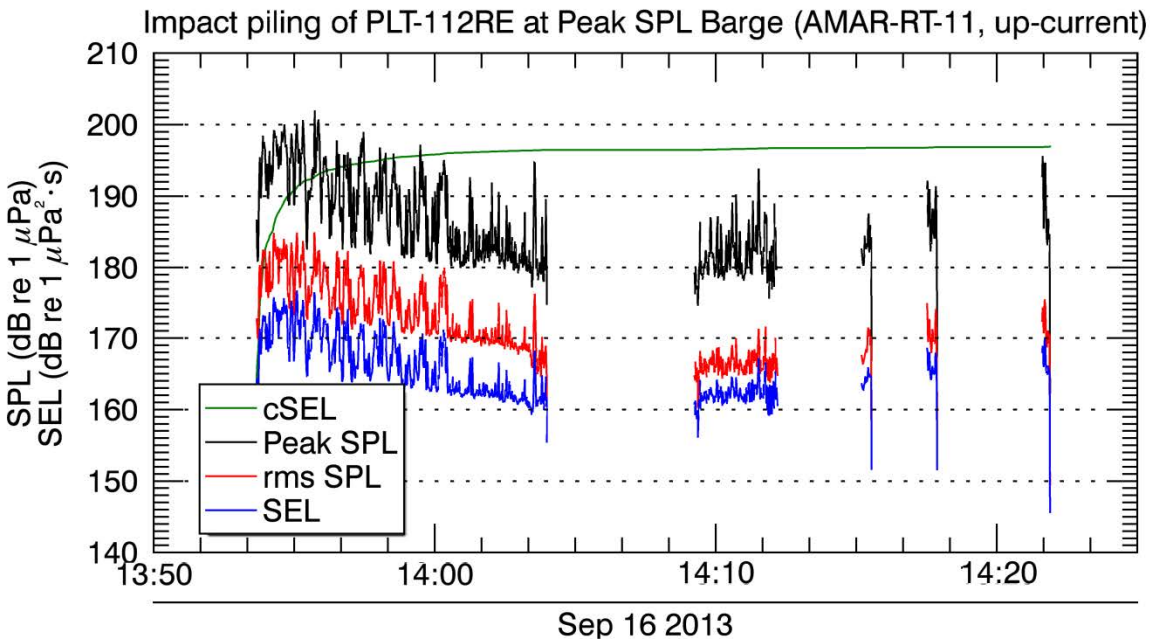


Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112RE measured 34.3 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

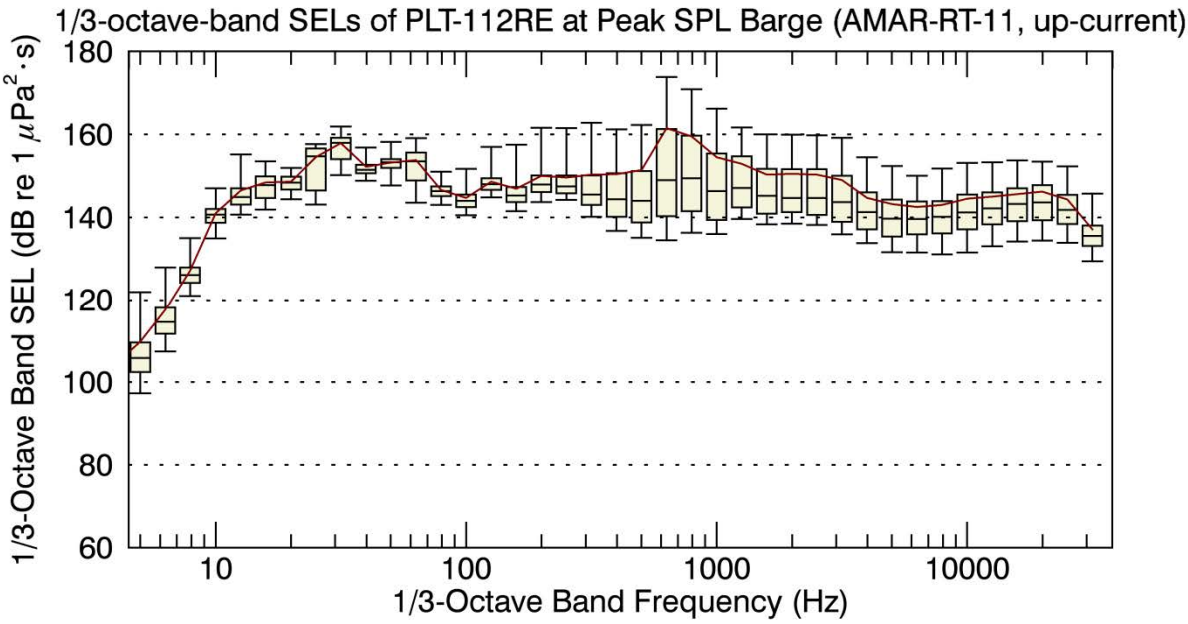


Figure 10. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112RE measured 34.3 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels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

Table 12. Sound levels for the pile driving of Test Pile PLT-112RE measured 34.3 ft from pile at location Peak SPL Barge usingAMAR-RT-11 (879 strikes).

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	202	184.9	176.8
L_5	197	181.4	173.3
L_{25}	191.1	176	168.4
L_{50}	185	171	164.1
L_{75}	181.4	168.6	162.2
L_{95}	179	165.2	160.8
L_{mean}	190.6	175.4	167.6

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

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

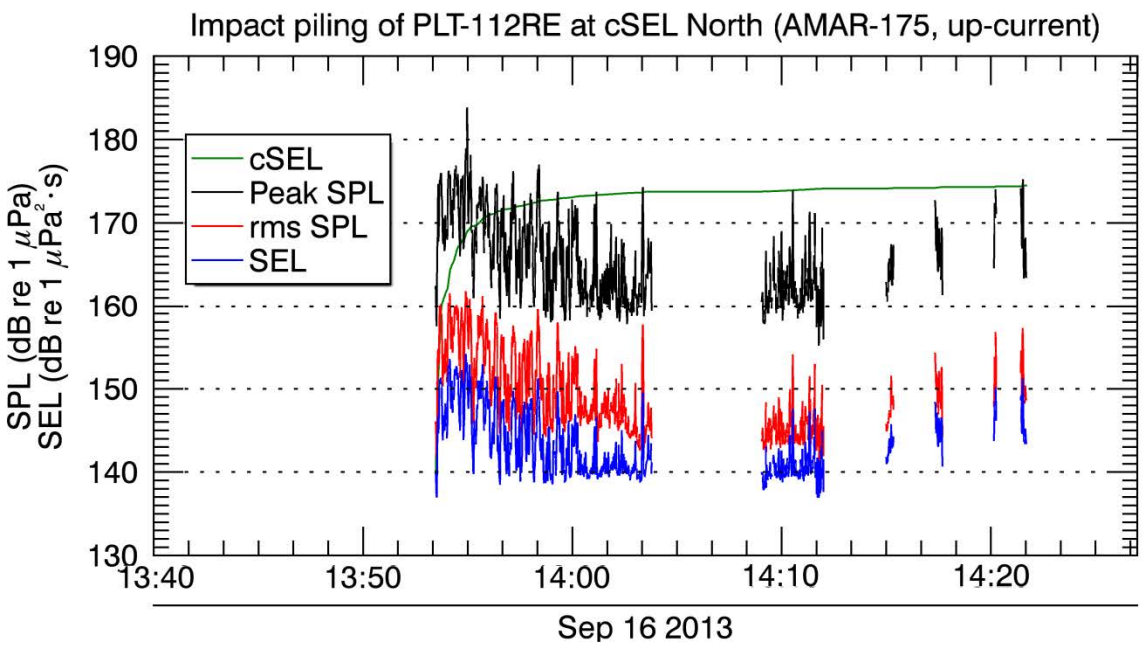


Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112RE measured 304 ft from the pile at location cSEL North using AMAR-175.

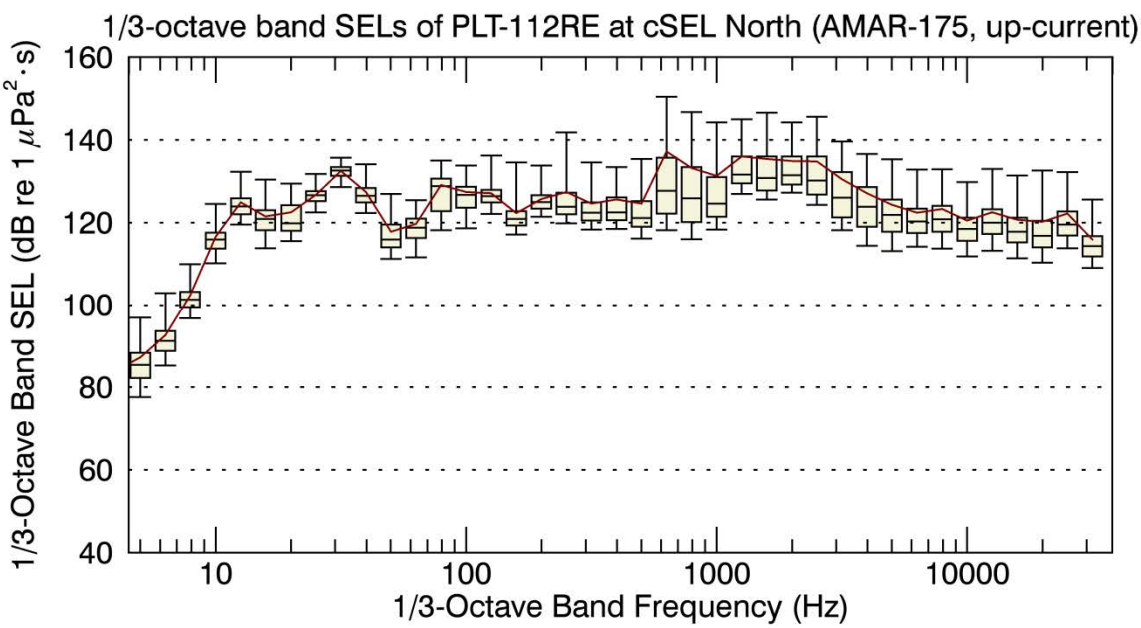


Figure 12. Distribution of 1/3-octave-band SELs for the pile driving of Test Pile PLT-112RE measured 304 ft from the pile at location cSEL North using AMAR-175. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}).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

Table 13. Sound levels for the pile driving of Test Pile PLT-112RE measured 304 ft from pile at location cSEL North using AMAR-175 (879 strikes).

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	183.9	161.8	154.2
L_5	174.7	158.5	151
L_{25}	169.4	153	145.9
L_{50}	164.5	148.3	142.1
L_{75}	161.4	145.9	140.1
L_{95}	159.2	143.6	139.1
L_{mean}	168.9	152.4	145.2

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

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

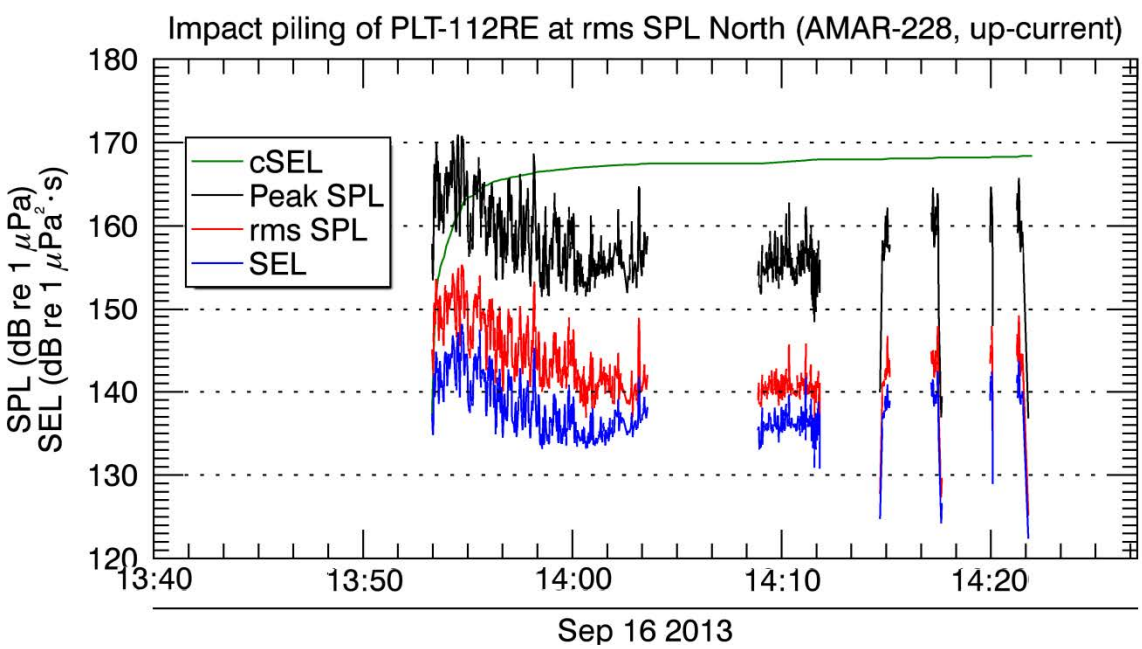


Figure 13. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-112RE measured 581 ft from the pile at location rms SPL North using AMAR-228.

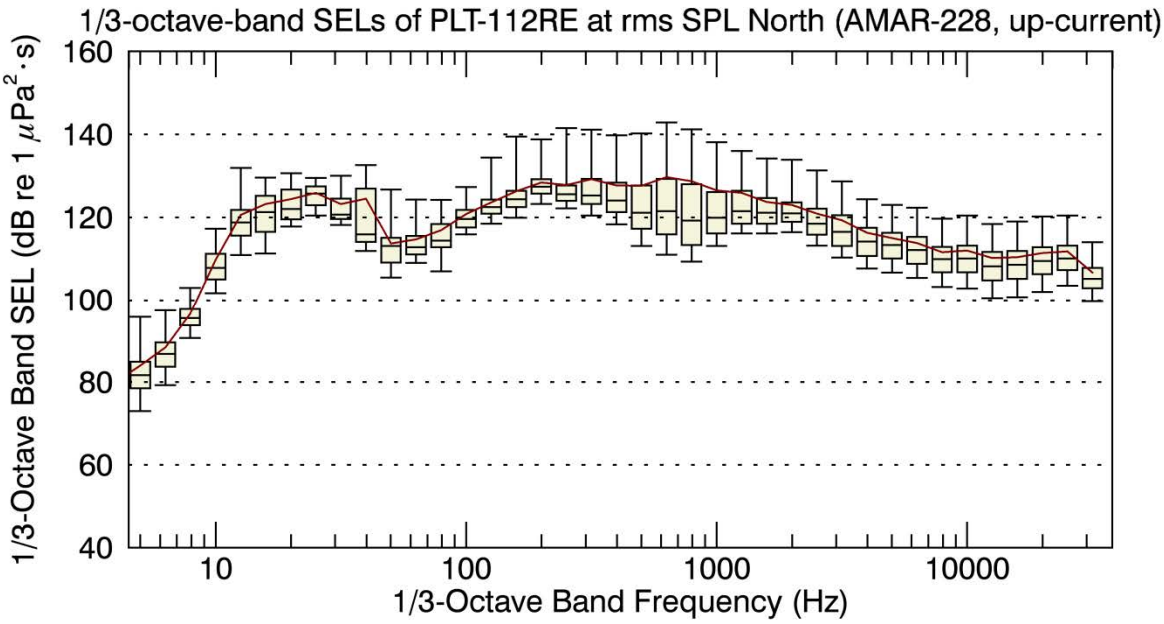


Figure 14. Distribution of 1/3-octave-band-band SELs for the pile driving of Test Pile PLT-112RE measured 581 ft from the pile at location rms SPL North using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels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

Table 14. Sound levels for the pile driving of Test Pile PLT-112RE measured 581 ft from pile at location rms SPL North using AMAR-228 (879 strikes).

Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa²s)
L_{max}	171	155.3	148.1
L_5	166.3	151.7	144.2
L_{25}	161.2	146.7	139.9
L_{50}	157.2	142.8	137
L_{75}	155	140.8	135.4
L_{95}	152.6	139.1	133.9
L_{mean}	160.7	146.1	139.3

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

Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 113 Installation

Daily Memorandum for 21 September 2013

Submitted to:

[redacted]

Authors:

[redacted]

JASCO Applied Sciences

[redacted]

21 September 2013
P001206-001

1. Summary

1.1. Pile Location and Monitoring Summary

Test Pile PLT-113 is a [redacted] pile driven at the site of the New NY Bridge on the east side of the navigation channel on 21 September 2013 (Table 1). One real-time acoustic monitoring system and two autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors, LLC (TZC) to measure sound levels at ranges of 46–772ft from the pile (Figure 1, Table 2). Pile driving occurred between 12:04–13:15 Eastern Daylight Time (EDT), and full flood tide occurred at 11:49 EDT, slowing to slack tide at 14:44 EDT.

The real-time system was located south of the pile template, at a range of 46 ft from the pile. Two autonomous systems were aligned along a radial north of the pile at distances of 148 ft and 772 ft.

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-113 activities, 21 September 2013.

Date:	21 September 2013
Pile-Driving Activity	
Test pile identifier:	PLT-113
Pile diameter:	[redacted]
Water depth:	9.8 ft
Hammer type:	Impact (IHC S-800)
Total hammer strikes:	1206
Total penetration:	123 ft
Net duration of pile driving (hh:mm:ss):	00:25:00*
Maximum single strike energy:	365.0 thousand foot-pounds (kip-ft), (495 kJ)
Total energy transferred:	322,681 kip-ft (437 MJ)
Noise Attenuation System (NAS)	
Two-tier unconfined bubble curtain airflow rate:	1050–1100 cubic feet per minute (cfm), 40–42 pounds per square inch (psi)
River conditions during piling:	Full Flood tide slowing during measurement 0–1.0 knots (0-0.5 meters per second [m/s]; Table 6)

*Value estimated based on rms SPL North plot for PLT 113 (see Attachment 1).

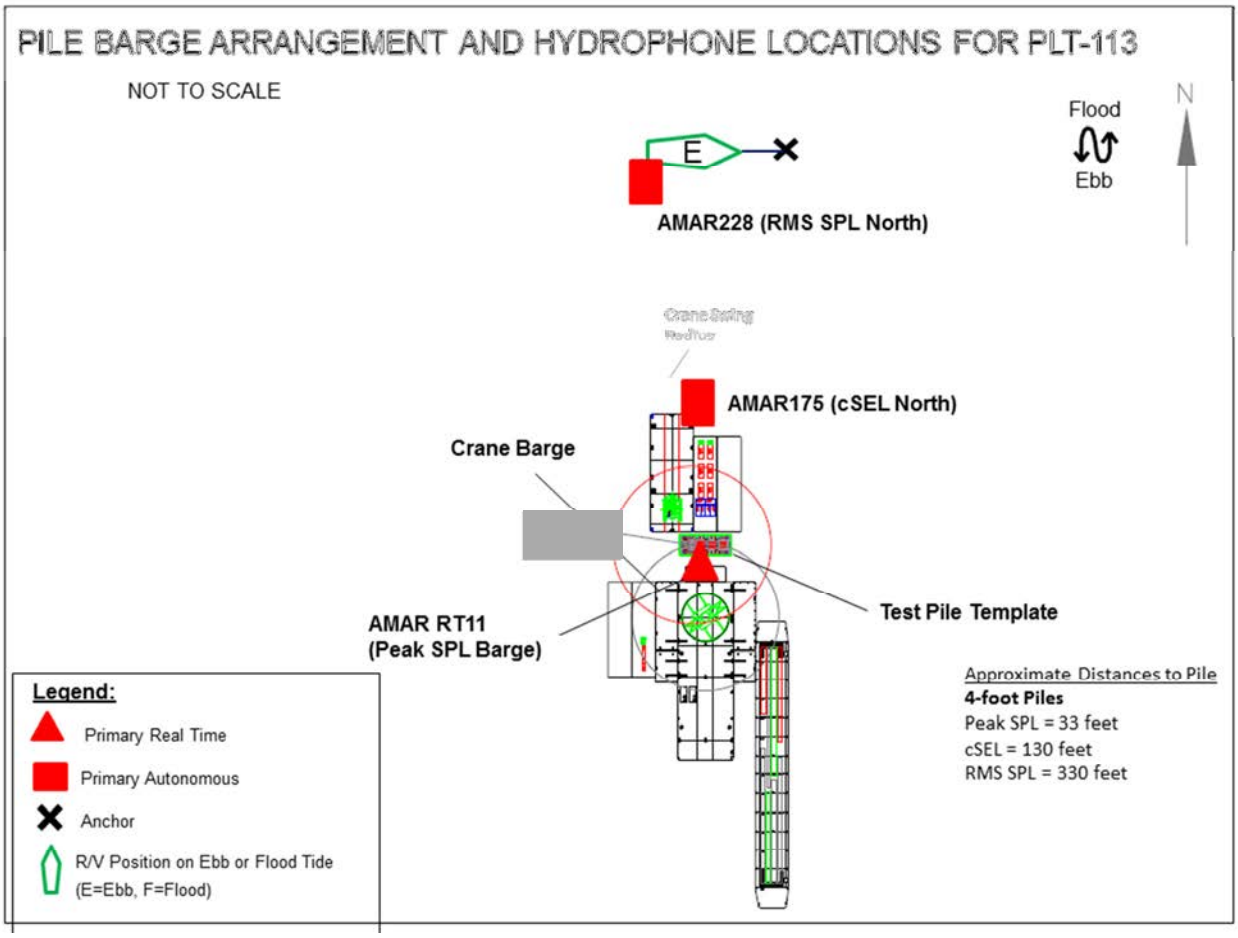


Figure 1. Plan view of pile and barge layout, 21 September 2013, Test Pile PLT-113.

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	46	9	192	198.5
cSEL North (down current)	AMAR-175	148	9	193.8	194.8
rms SPL North (down current)	AMAR-228	772	9.8	172	173.5

* 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 19 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 SEL (cSEL) isopleth was estimated to be 458 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 458 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 radii for the NMFS physiological and behavioral thresholds.

Criteria	Estimated mean radius (ft)
206 dB re 1 µPa peak SPL	9.3
187 dB re 1 µPa2·s cSEL*	229
150 dB re 1 µPa rms SPL (1 s integration time)	942

* At the end of pile driving

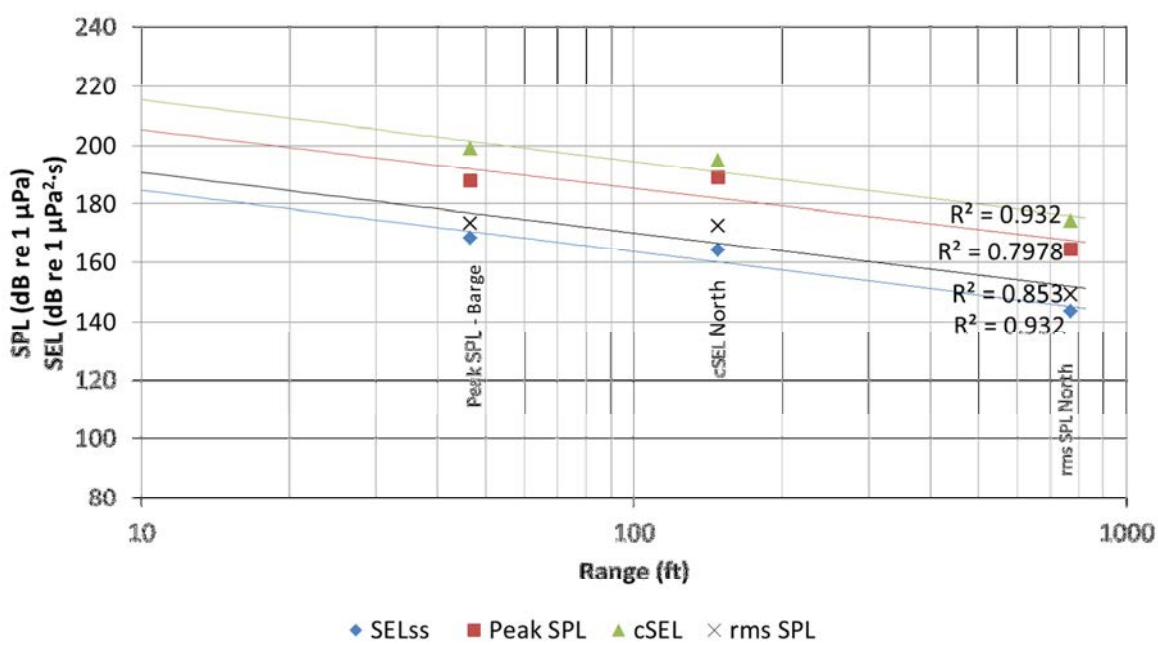


Figure 2. Regression based on mean values of the peak SPL, rms SPL, and single strike SELs from each recorder from pile driving of Test Pile PLT-113, 21 September 2013. Single Strike SEL (SEL_{ss}), peak SPL, and rms SPL are instantaneous values. The cSEL represents the total sound energy measured during the pile driving.

1.3. Observations

During the pile driving at PLT-113 the NAS air pressure and airflow were nearly constant at 40–42 psi and 1050-1100 cfm (Table 5). Moderate flood currents below 1 knot occurred throughout the pile driving. The hammer energy increased from 140-365 kip-ft (Figure 3, Figure 4). There were no patterns detected for measured sound levels at the three recorders relative to hammer energy. However, at all measurement locations the measured sound levels tended to increase during the pile driving. At location Peak SPL Barge it appears that there may be correlation between the hammer energy and the measured sound levels; however, the variability of the peak SPL and rms SPL during the pile driving with hammer energies of 140-160 kip-ft does not fit this trend (Figure 3).

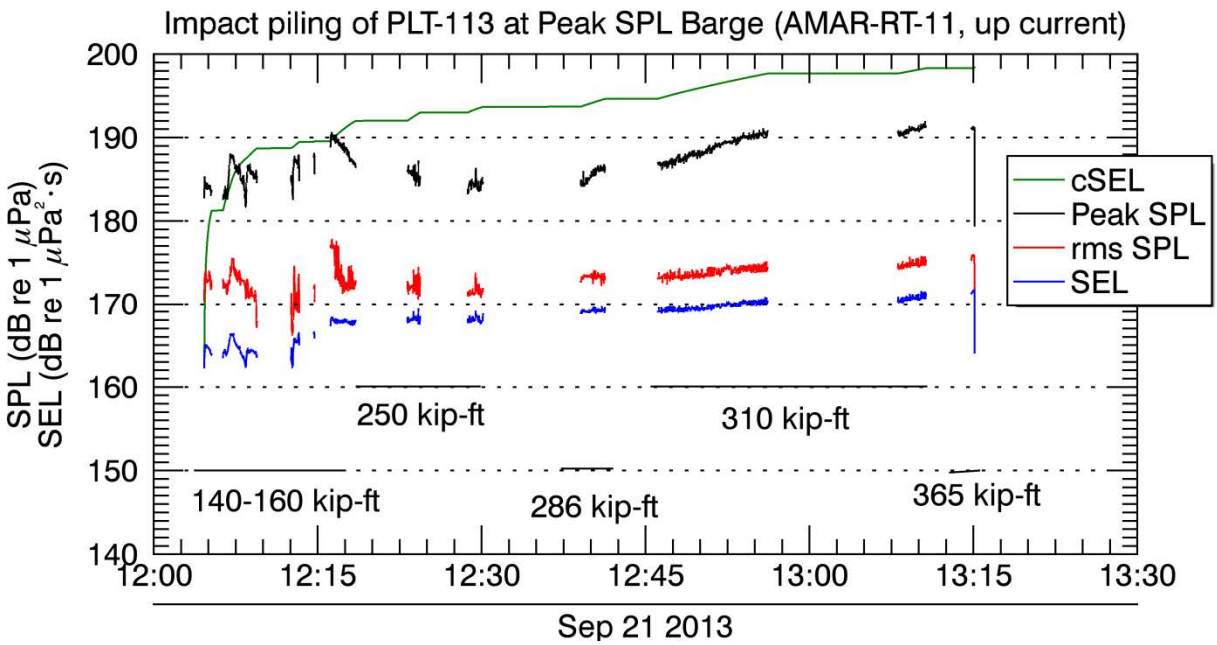


Figure 3. Peak SPL, rms SPL, SEL, and cSEL for the pile driving of Test Pile PLT-113 measured 46 ft from the pile at location Peak SPL Barge using AMAR-RT-11. The hammer energy (kip-ft) is shown along the bottom of the plot.

At location cSEL North the measured sound levels rose steadily during the piling at 150 and 250 kip-ft. During the pile driving at 310 and 365 kip-ft the sound levels at cSEL North were steady and very near the values at Peak SPL Barge, despite the range being three times farther away (Figure 6, Figure 8, and Table 2). Sound levels at cSEL North and rms SPL North increased steadily throughout the pile driving (Figure 8 and Figure 10). In Figure 3 it appears that the sound levels at Peak SPL Barge may increase with increases in hammer energy, especially after 12:30. However the sound levels increase steadily when the hammer energy is constant, especially at 310 kip-ft.

The relatively high sound levels at cSEL North were responsible for the increased range to the 187 dB re 1 μPa^2·s isopleth compared to other PLT measurements. The mechanism that caused

this sound level increase is unknown. There is no indication that this effect would cause the sound levels to exceed the NMFS and NYSDEC permit thresholds.

2. Activity Logs

2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 21 September 2013.

Table 4. JASCO and construction activities for 21 September 2013.

Time (EDT)	Activity
09:00	Arrive at dock, prep recorders
09:40	Leave dock for job site
10:00	Transfer to barge, deploy AMAR-175
11:30	Deploy AMAR-RT from barge and AMAR-228 from Alpine vessel
11:35	Start picking hammer
12:00	Dredges moving close to north side of pile barge and AMAR-175
12:04	Start piling
13:00	Dredging within 6 ft of the north side of the pile barge and AMAR-175
13:15	Stop piling
13:20	Retrieve recorders
14:30	At dock; data downloaded, secured

2.2. Pile Driving Logs

2.2.1. NAS

NAS used: Two-tier unconfined bubble curtain

NAS Settings: 1050–1100 cfm, 40–42 psi

Table 5. NAS setting recorded during piling at Test Pile PLT-113, 21 September 2013.

Time (EDT)	Volume/min (cfm)	Pressure (psi)
12:04	1050–1100	40–42
12:06	1050–1100	40–42
12:12	1050–1100	40–42
12:14	1050–1100	40–42
12:16	1050–1100	40–42
12:23	1050–1100	40–42
12:28	1050–1100	40–42
12:38	1050–1100	40–42
12:46	1050–1100	40–42
13:07	1050–1100	40–42
13:14	1050–1100	40–42

2.2.2. Impact Hammering Log

Total Energy: 322,681 kip-ft (437 MJ)

Total number of strikes: 1206

Maximum per-strike energy: 365.0 kip-ft, (495 kJ)

Net piling duration (hh:mm:ss): 00:07:47

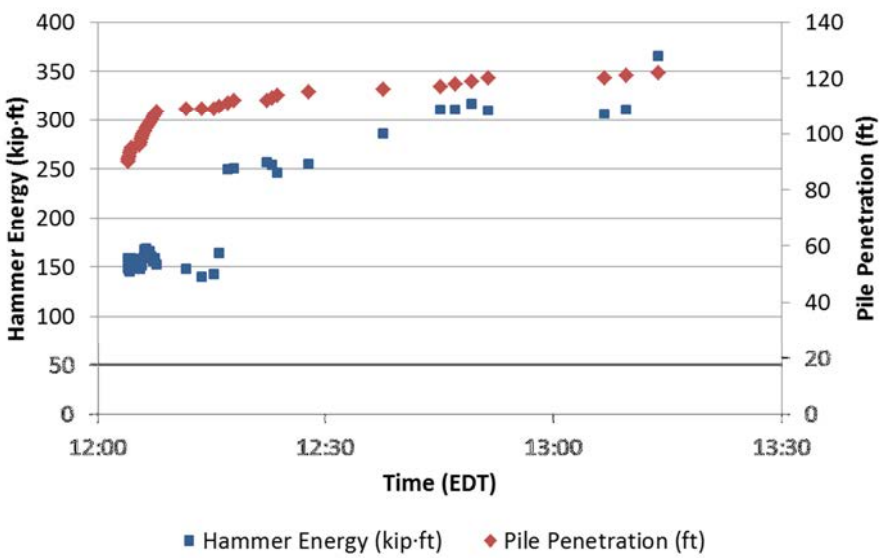


Figure 4. Hammer energy (kip-ft) and pile penetration (ft) for installation of Test Pile PLT-113, 21 September 2013.

3. Weather and River Conditions

Table 6 provides the predicted currents at the project site on 21 September 2013. Figure 5 provides the measured speed of sound in water, based on a conductivity, temperature, depth (CTD) cast. Acoustic Doppler Current Profiler (ADCP) measurements for 21 September 2013 are not available due to a failure of the equipment.

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

Weather conditions:	Sunny, ~5 knot southerly wind
Full ebb current:	n/a
Slack current:	14:44
Full flood current:	11:49, 1.3 knots

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

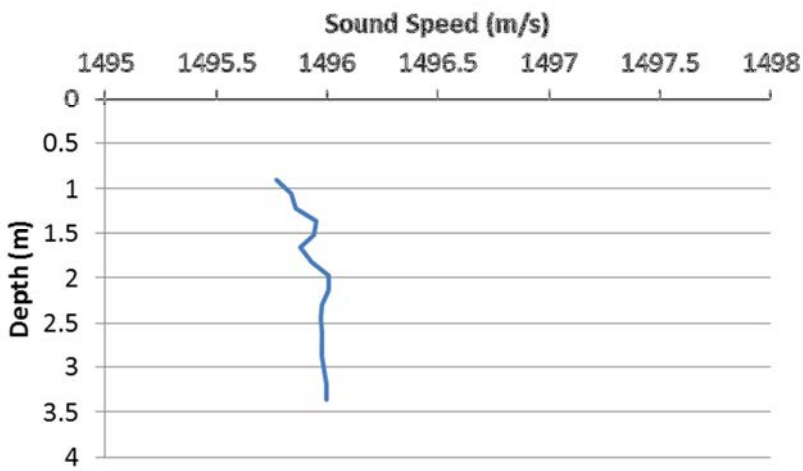


Figure 5. CTD cast performed at 12:30 EDT from the Alpine vessel, located 772 ft NE of Test Pile PTL-113 (41.07280 N, 73.87119 W).

4. Monitoring Equipment

4.1. Real-time Monitoring Equipment

Table 7 provides information on the real-time monitoring equipment used on 21 September 2013.

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

Table 7. Real-time monitoring equipment for Test Pile PTL-113, 21 September 2013.

Equipment used		Units deployed
Acoustic data logger		
Model:	AMAR-RT (JASCO Applied Sciences)	1
SpectroPlotter version:	6.0.1	1
Hydrophone		
Model:	M8KC (GTI)	1
AMAR-RT-11 sensitivity:	-210.9 dB re 1 V/µPa	1
Other		
Hydrophone calibrator:	Pistonphone Type 42AC (G.R.A.S. Sound and Vibration)	1
CTD profiler:	Minos X (AML Oceanographic)	1
ADCP:	RDI Teledyne Workhorse Sentinel 1200 kHz (not functional)	1

Table 8. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 21 September 2013.

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
Peak SPL Barge	AMAR-RT11	41.07057	73.8717	11:05	9	46

4.2. Autonomous Monitoring Equipment

Table 9 provides information about the autonomous monitoring equipment used on 21 September 2013.

Table 10 provides the locations of the autonomous recorders.

Table 9. Autonomous recorder information for Test Pile PTL-113, 21 September 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:	-199.84 dB re 1 V/µPa	1

Table 10. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 21 September 2013

Station	Recorder ID	Latitude (°N)	Longitude (°W)	Deployment time (EDT)	Water depth (ft)	Distance to pile (ft)
cSEL North	AMAR-175	41.07113	-73.87177	10:41	9	148
rms SPL North	AMAR-228	41.07280	-73.87119	11:25	9.8	772

Appendix A. Pile Driving Plots

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

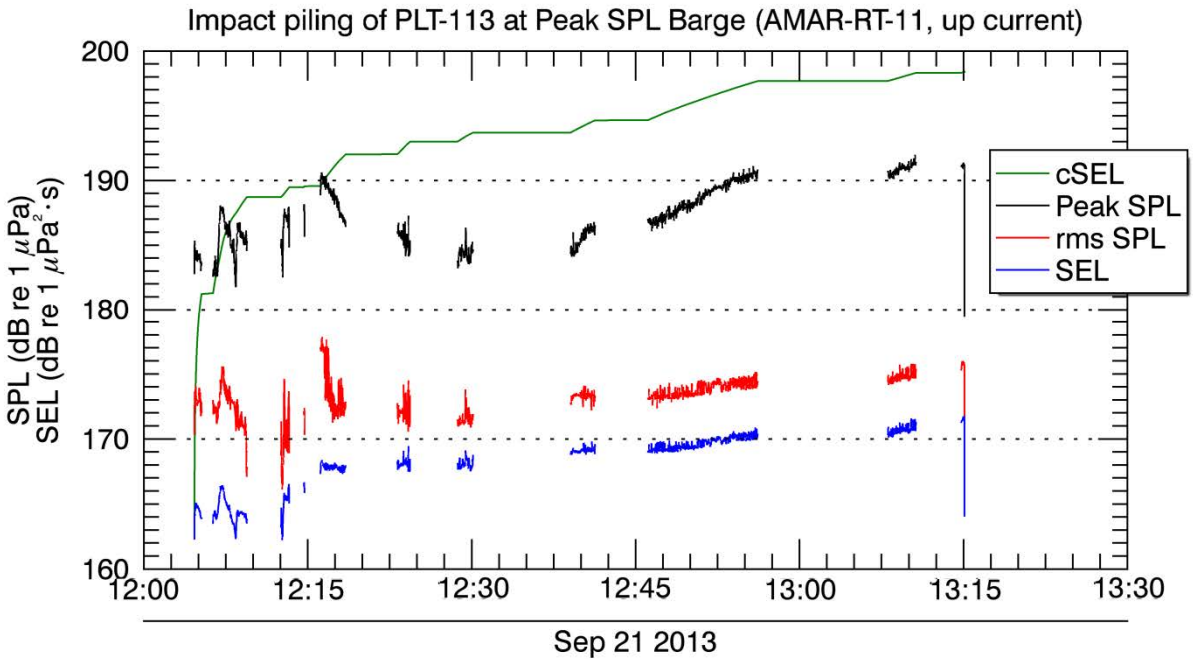


Figure 6. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL for the pile driving of Test Pile PLT-113 measured 46 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

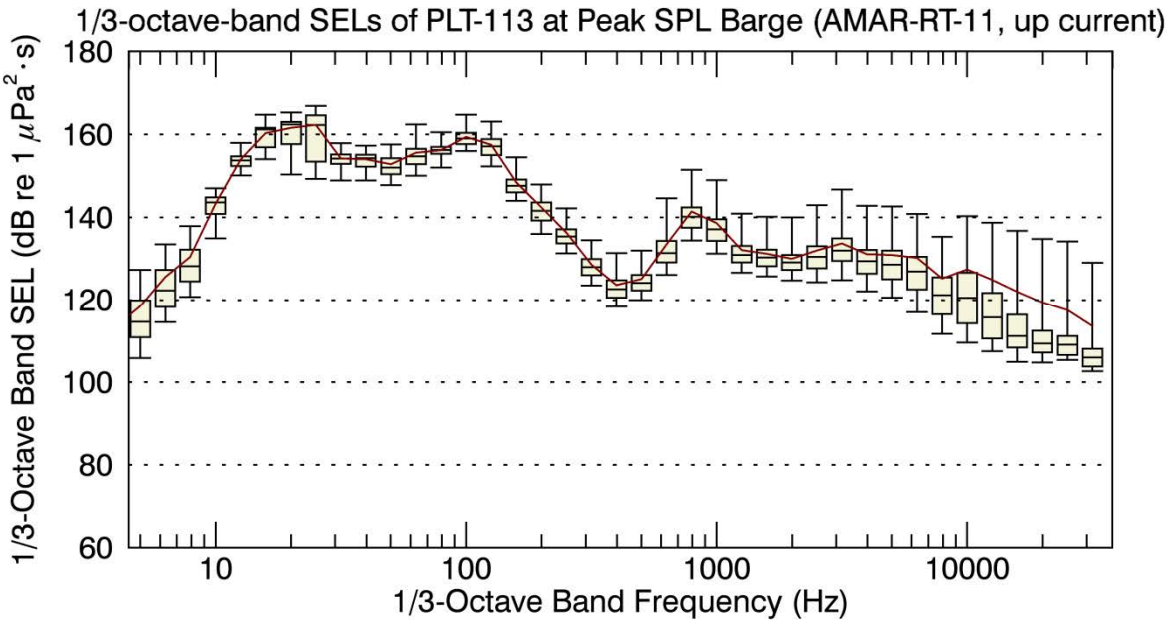


Figure 7. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-113 measured 46 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). 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-113 measured 46 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)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	192	177.8	171.7
L_5	190.9	175.3	170.6
L_{25}	189.3	174.1	169.7
L_{50}	187.1	173.3	168.2
L_{75}	185.4	172.3	165.4
L_{95}	183.6	170.8	163.8
L_{mean}	187.8	173.4	168.3

* 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}).

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

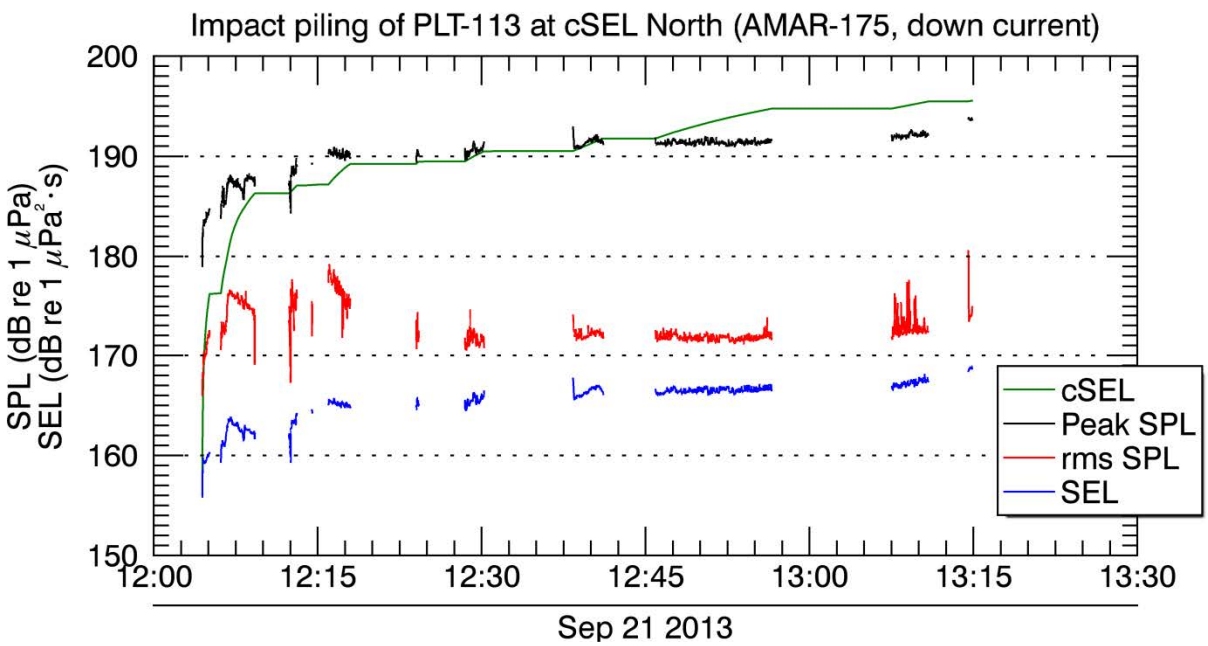


Figure 8. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL for the pile driving of Test Pile PLT-113 measured 148 ft from the pile at location cSEL North using AMAR-175.

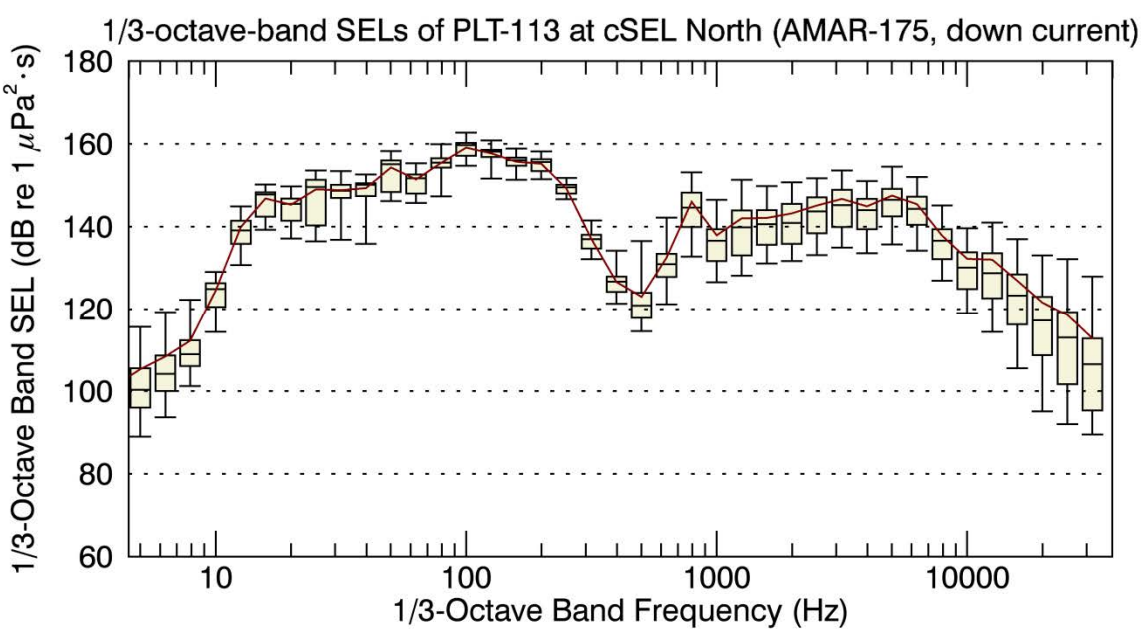


Figure 9. Distribution of1/3-octave-band SELss for the pile driving of Test Pile PLT-113 measured 148 ft from the pile at location cSEL North using AMAR-175. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). Lower error bars indicate the 95% exceedance percentiles (L_{95}). The maroon line indicates the arithmetic mean (L_{mean}).

Table 12. Sound levels for the pile driving of Test Pile PLT-113 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)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	193.8	179.2	168.8
L_5	191.9	176.5	167
L_{25}	191.3	174.5	166.3
L_{50}	189.7	171.9	164.7
L_{75}	179.8	159.6	155.9
L_{95}	171.6	155.8	151.8
L_{mean}	189	172.6	164.1

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

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

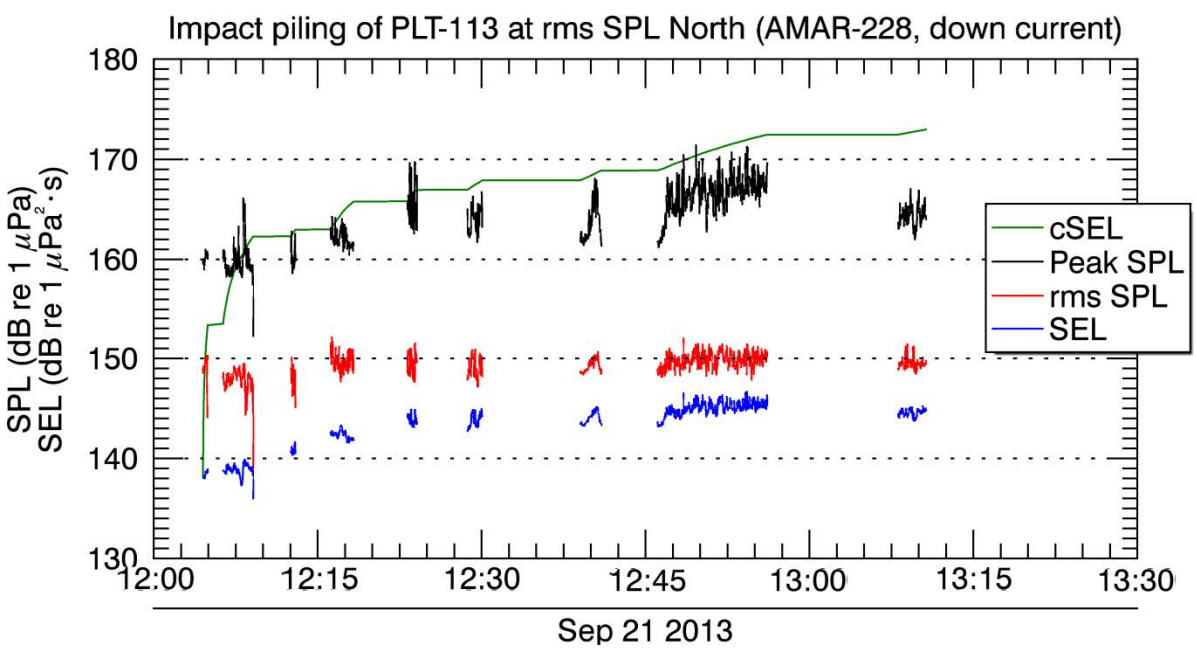


Figure 10. *Impact Pile Driving*: Peak and rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-113 measured 772 ft from the pile at location rms SPL North using AMAR-228..

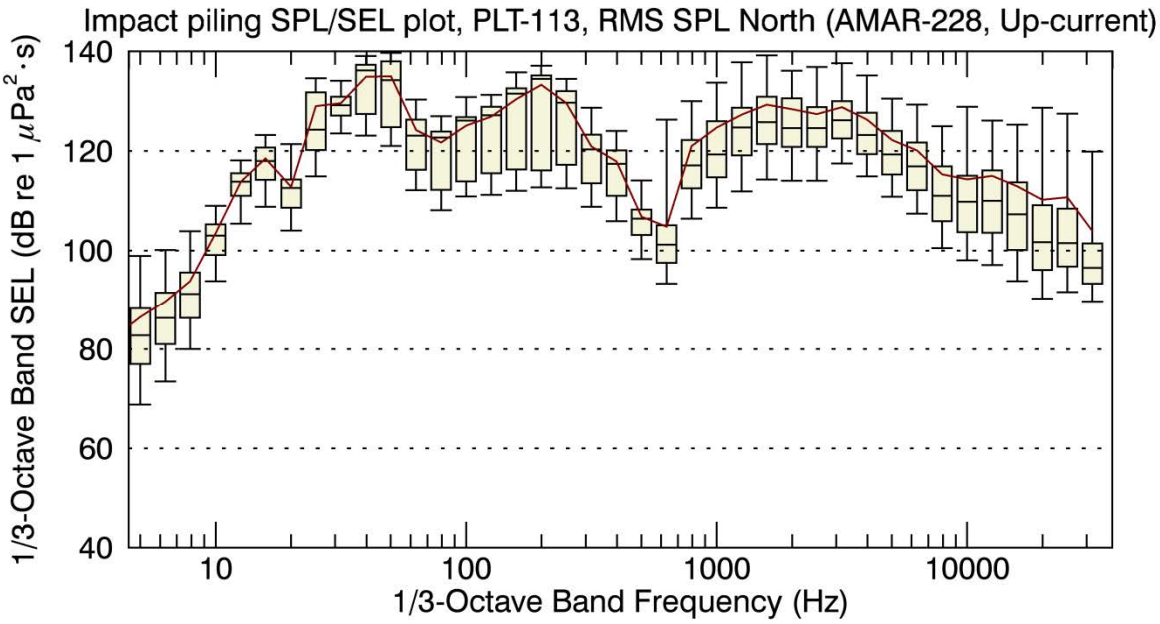


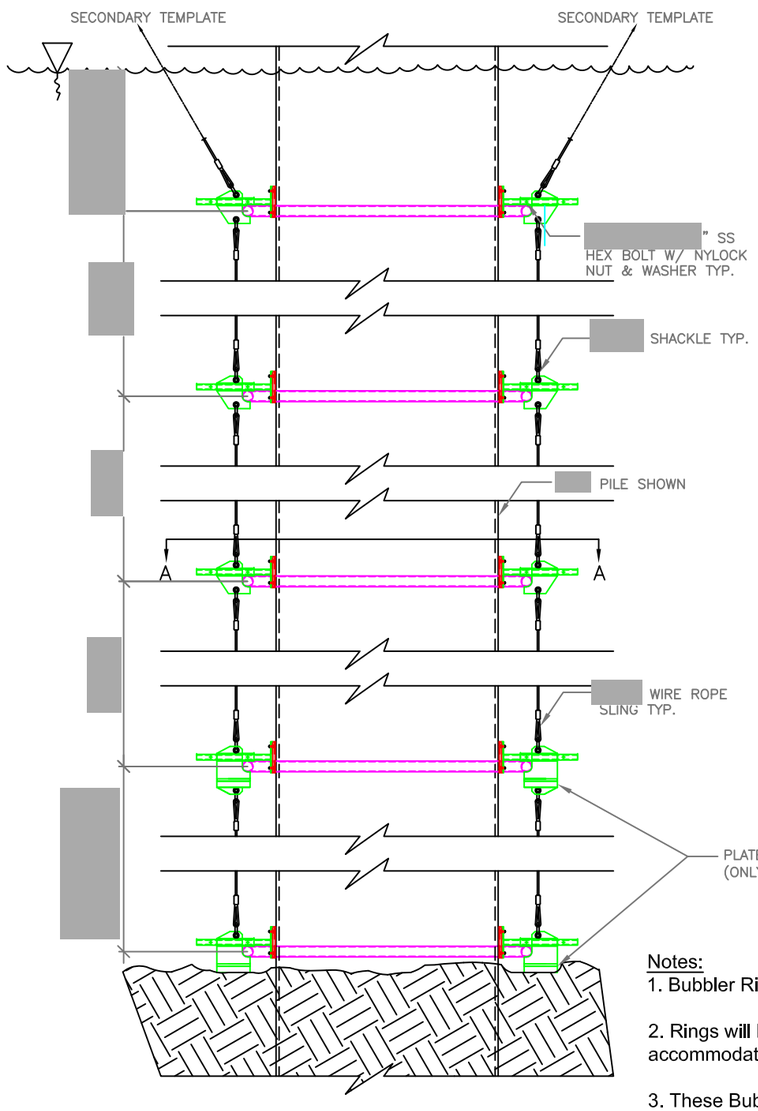
Figure 11. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-113 measured 772 ft from the pile at location rms SPL North using AMAR-228. Beige bars indicate the first, second, and third quartiles (L_{25}, L_{50}, and L_{75}). Upper error bars indicate the maximum levels (L_{max}). 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-113 measured 772 ft from the pile at location rms SPL North using AMAR-228.

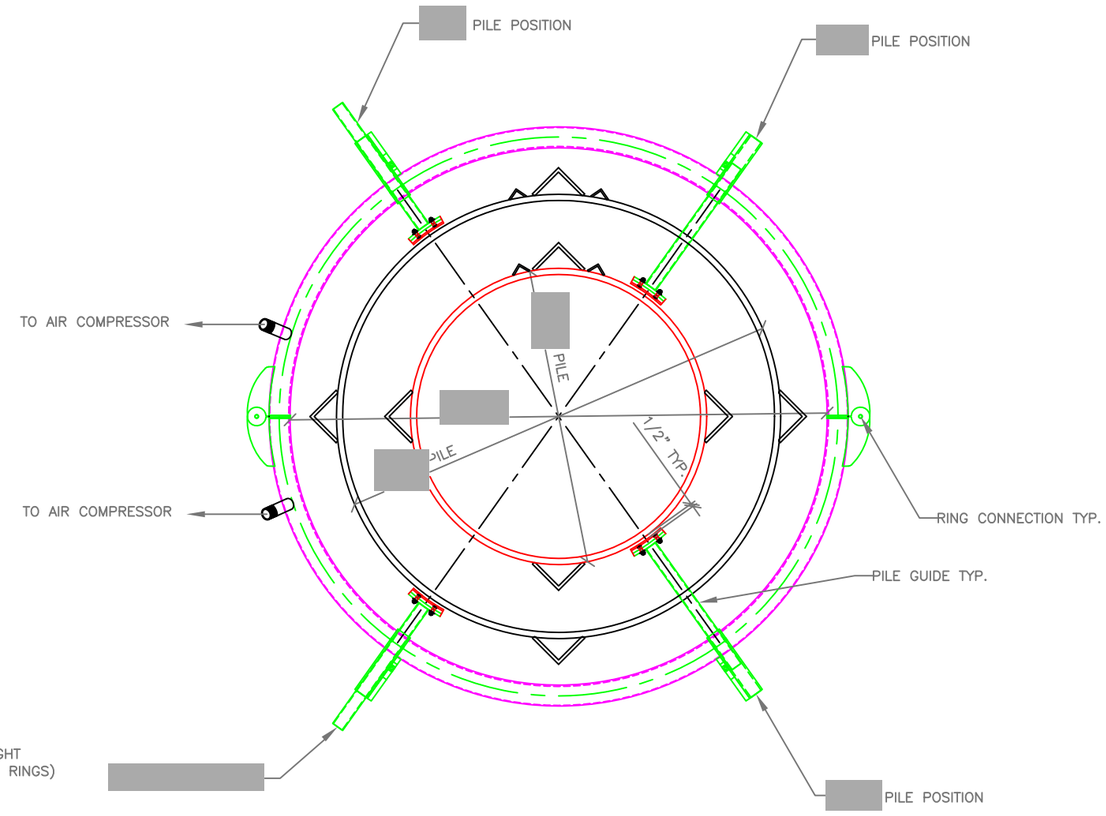
Sound level statistic*	peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	Single strike SEL (dB re 1 µPa^{2}s)
L_{max}	171.5	152.2	146.7
L_5	168.4	150.9	145.7
L_{25}	166.1	150	144.9
L_{50}	163.6	149.3	143.8
L_{75}	161.1	148.5	140.4
L_{95}	158.8	147.2	138.5
L_{mean}	164.6	149.3	143.5

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

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



ELEVATION - BUBBLER RINGS
SCALE: NTS



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

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

3. These Bubbler Rings can be used on diameter piles

A
-
PLAN - BUBBLER RINGS
SCALE: NTS

DRAFTED BY:
CHECKED BY:
DESIGNED BY:
CHECKED BY:
DESIGN SUPERVISOR:

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

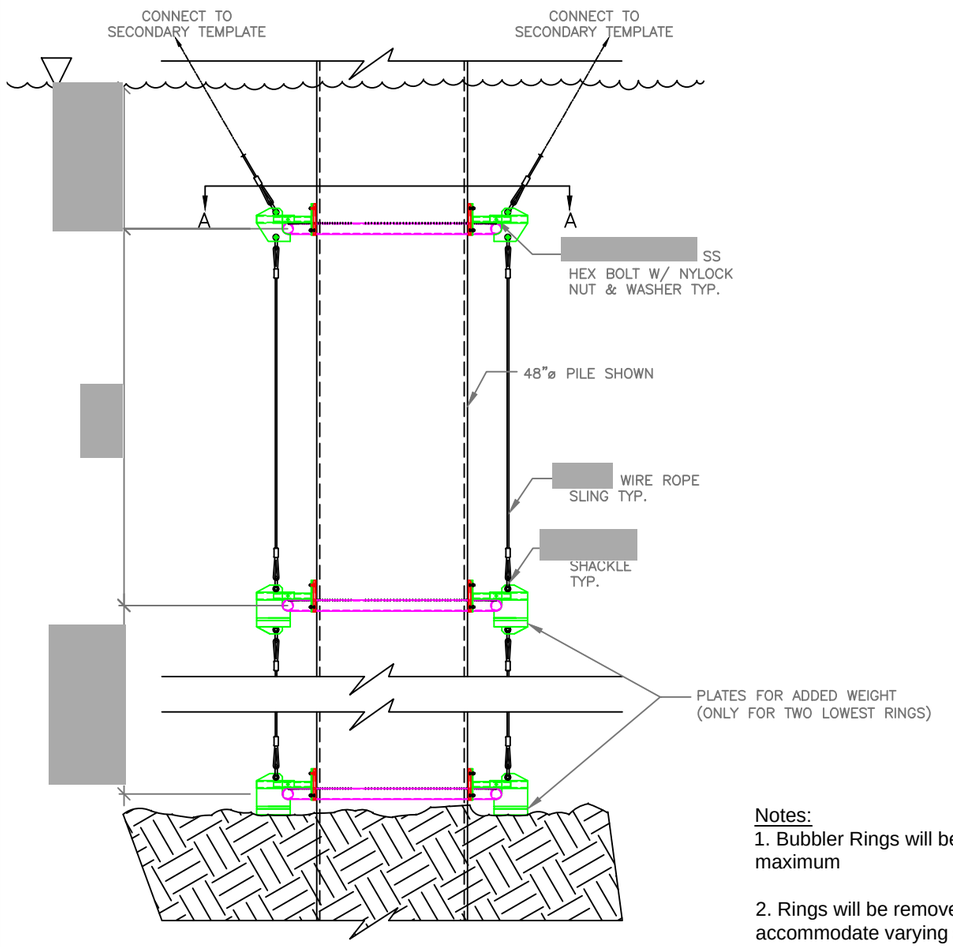
NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

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

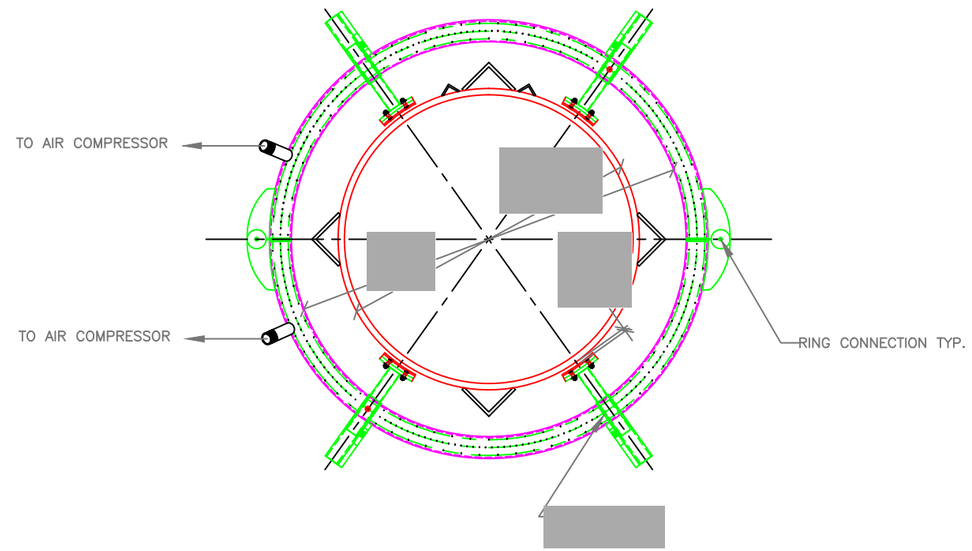
CONTRACT NUMBER: –
DATE: 5/20/13
DRAWING NUMBER: 1UBCR

DOCUMENT TRACKING CODE: -



ELEVATION - BUBBLER RINGS 48" PILES

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 only

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

DOCUMENT TRACKING CODE:

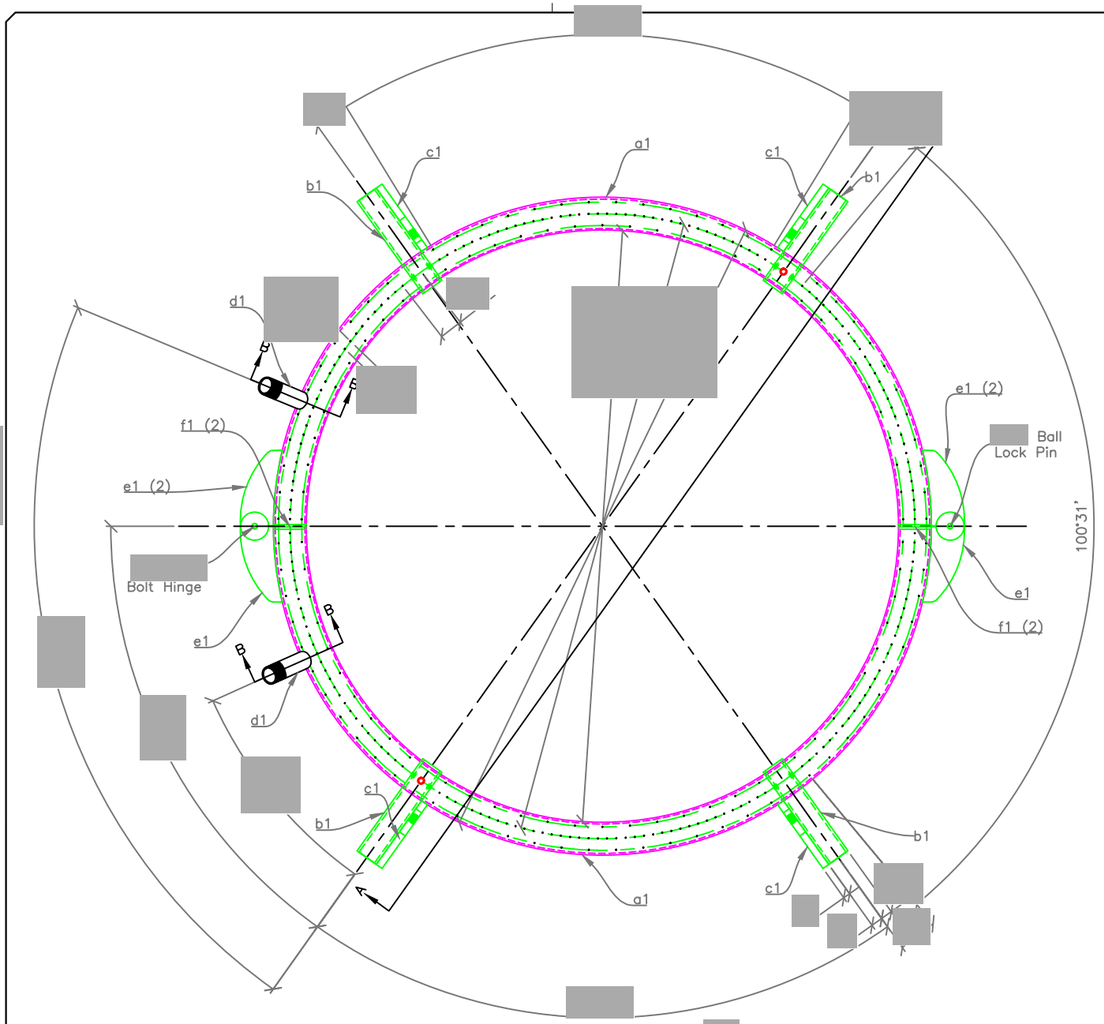
DESIGN SUPERVISOR:

DESIGNED BY:

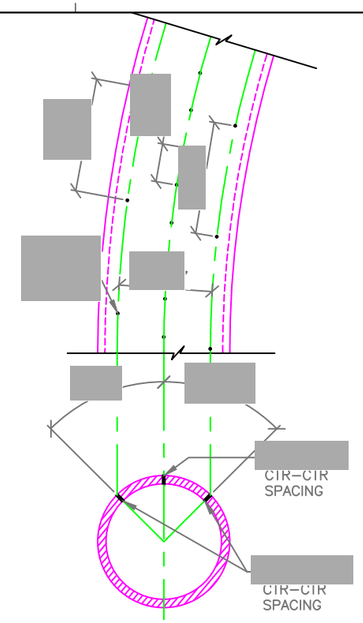
CHECKED BY:

DRAFTED BY:

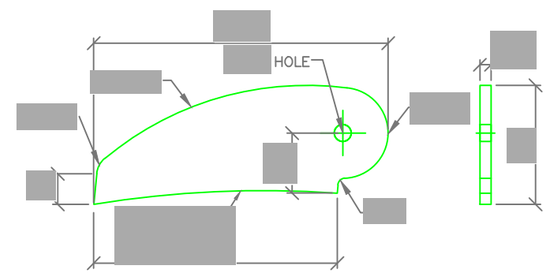
CHECKED BY:



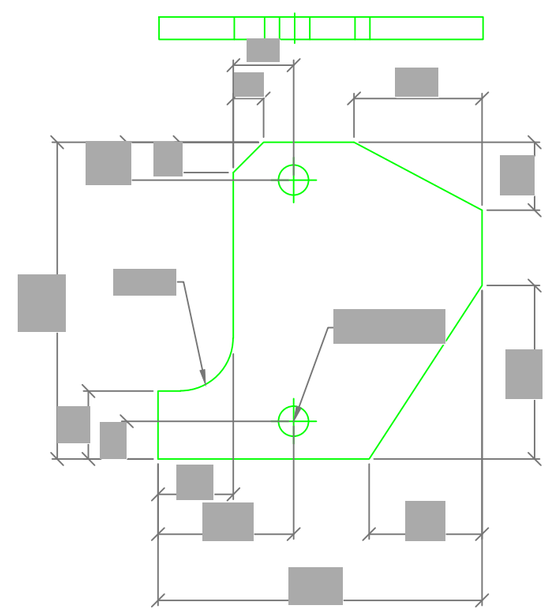
MK 1T - TOP BUBBLER RING FOR PILES
SCALE: NTS



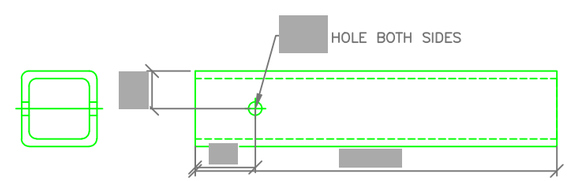
TYPICAL SECTION - HOLE LAYOUT
SCALE: NTS



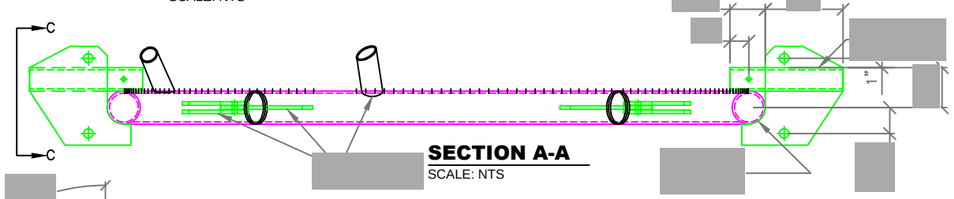
e1-PLATE - T6061 ALUMINUM
SCALE: NTS



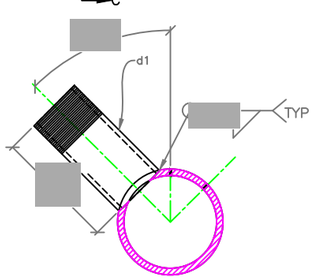
c1-PLATE - T6061 ALUMINUM
SCALE: NTS



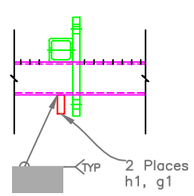
b1-TS - T6061 ALUMINUM
SCALE: NTS



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

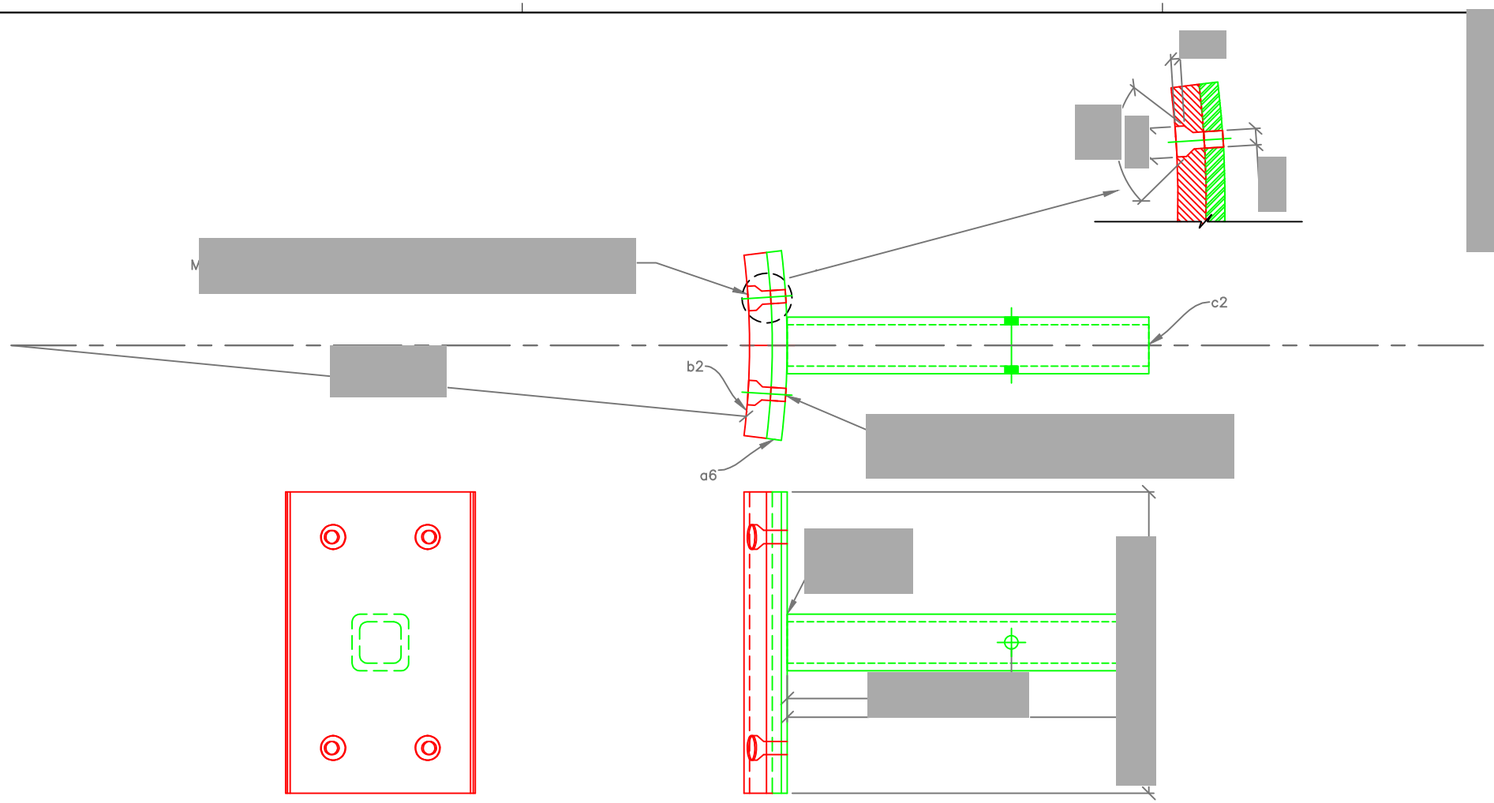
TAPPAN ZEE CONSTRUCTORS, LLC

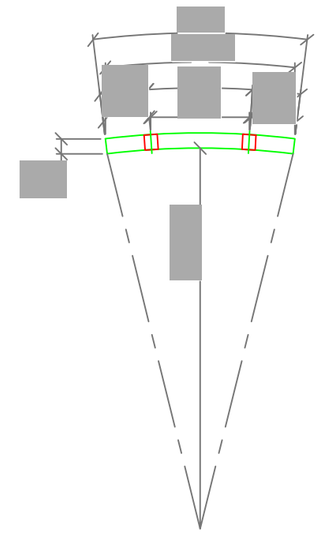
TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS

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

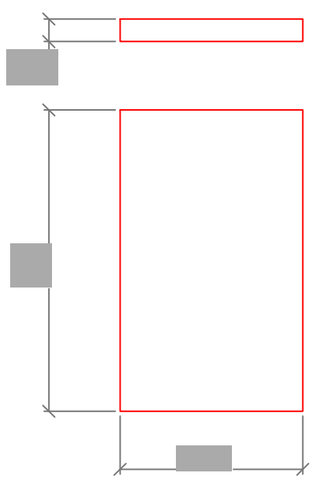
DOCUMENT TRACKING CODE: -

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

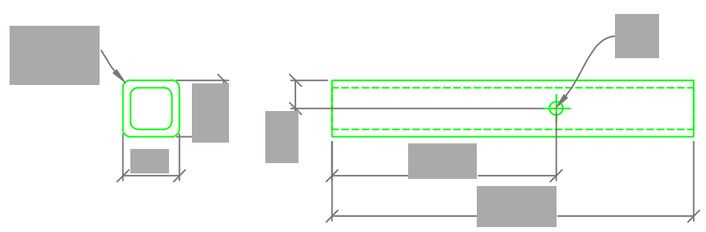




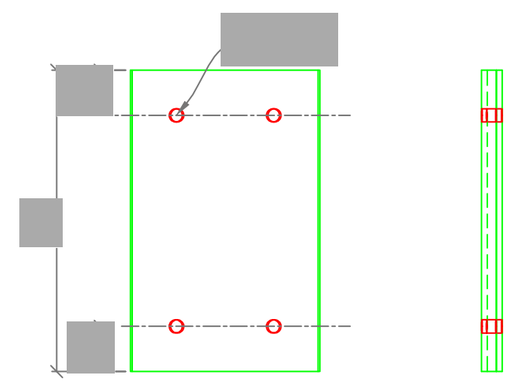
MK 3A - UHMW GUIDES FOR PILES
SCALE: NTS



b2 - UHMW
SCALE: NTS



c2 - SQ T6061 ALUMINUM
SCALE: NTS



a6 - PLATE T6061 ALUMINUM
SCALE: NTS

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

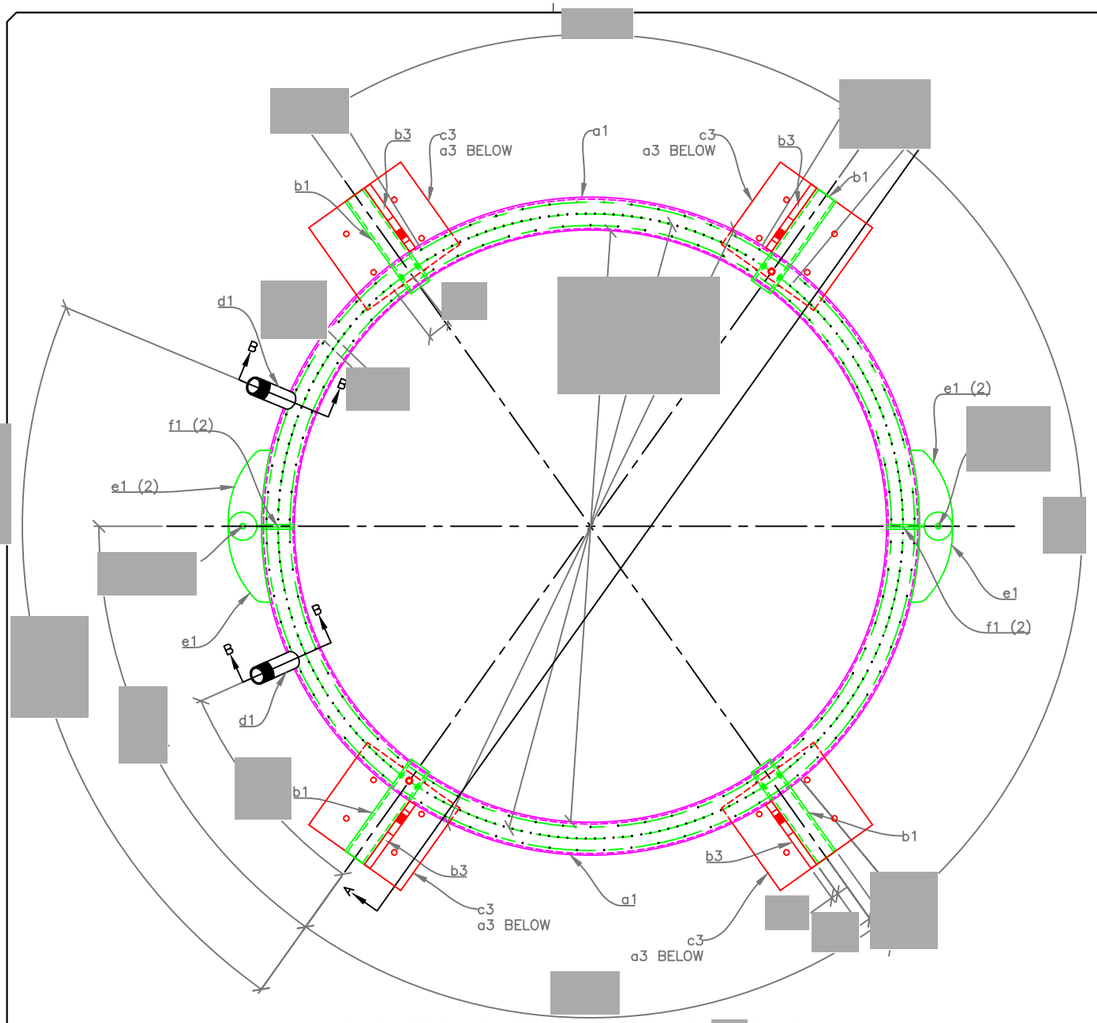
NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

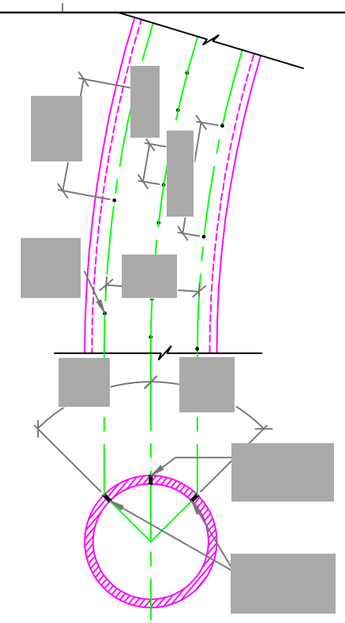
TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS

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

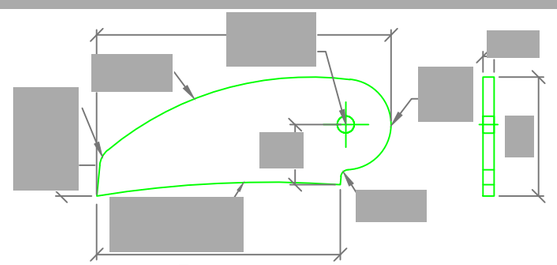
DESIGN SUPERVISOR:
DESIGNED BY:
DRAFTED BY:
CHECKED BY:
CHECKED BY:
DOCUMENT TRACKING CODE:



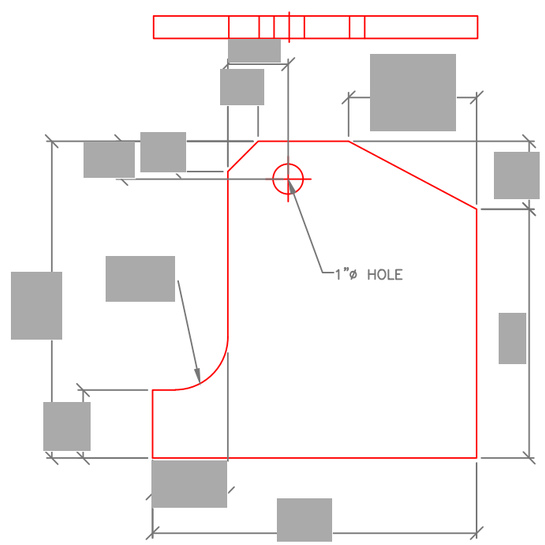
MK 1B - BOTTOM BUBBLER RING FOR [redacted] PILES
SCALE: NTS



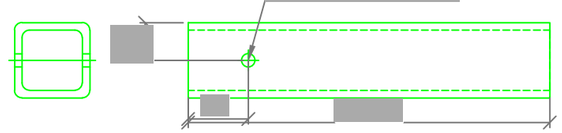
TYPICAL SECTION - [redacted] HOLE LAYOUT
SCALE: NTS



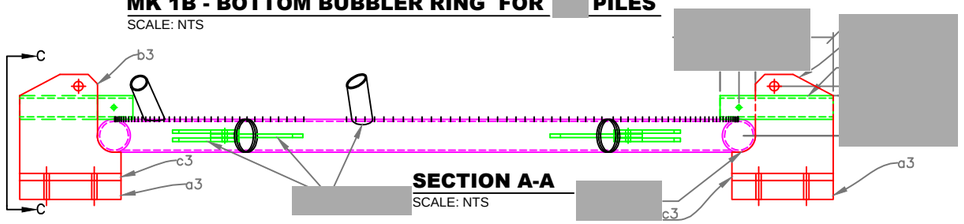
e1-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS



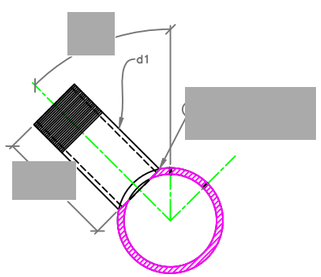
b3-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS



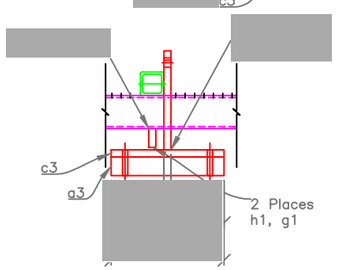
b1-TS [redacted] T6061 ALUMINUM
SCALE: NTS



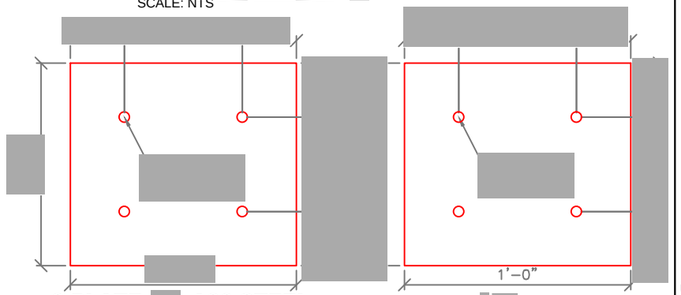
SECTION A-A
SCALE: NTS



SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS



SECTION C-C
SCALE: NTS



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

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

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

NEW YORK STATE THRUWAY AUTHORITY

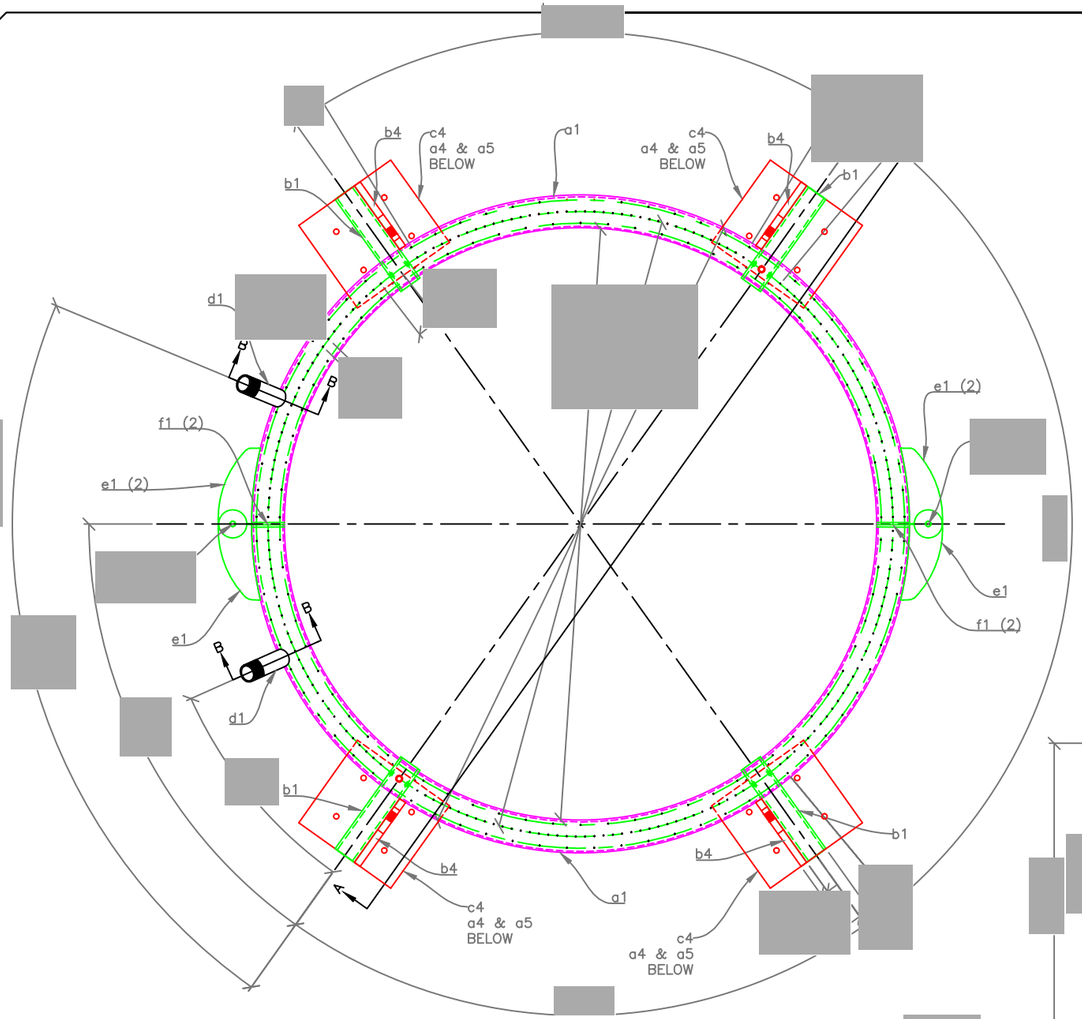
TAPPAN ZEE CONSTRUCTORS, LLC

TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS [redacted]

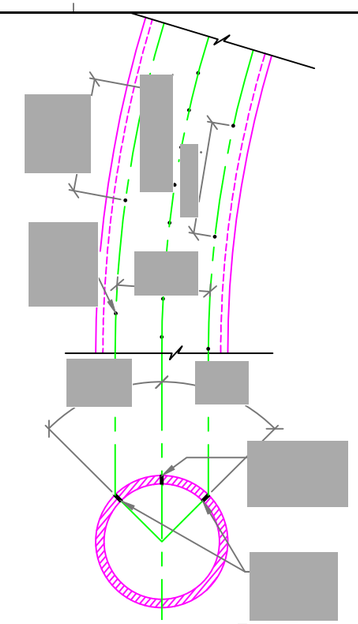
CONTRACT NUMBER: –
DATE: 5/19/13
DRAWING NUMBER: 5UBCR

DOCUMENT TRACKING CODE: -

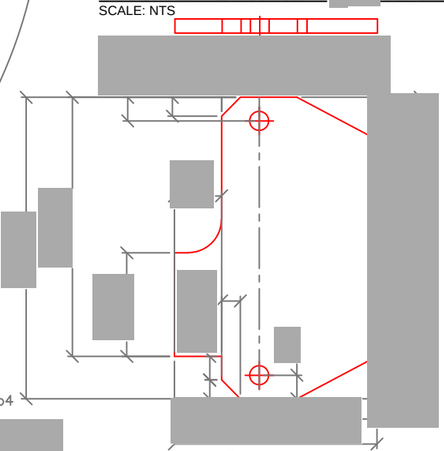
DESIGN SUPERVISOR: – DESIGNED BY: – CHECKED BY: – DRAFTED BY: – CHECKED BY: –



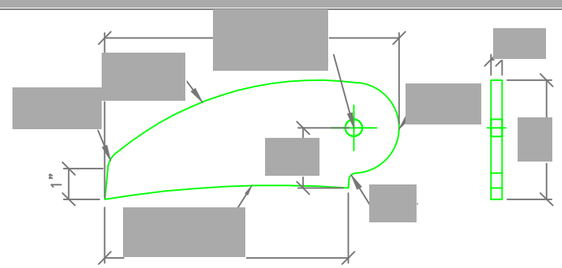
MK 1M - MIDDLE BUBBLER RING FOR PILES
SCALE: NTS



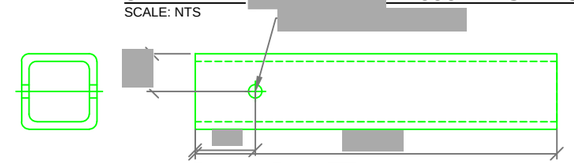
TYPICAL SECTION - HOLE LAYOUT
SCALE: NTS



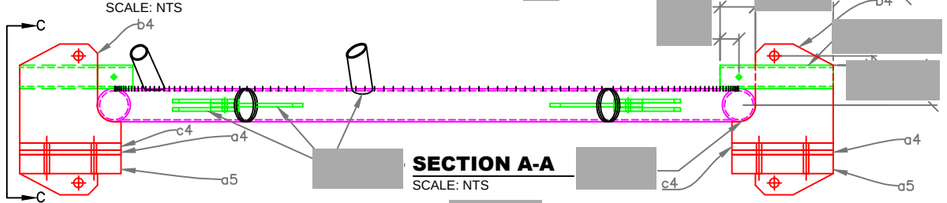
b4-PLATE - T6061 ALUMINUM
SCALE: NTS



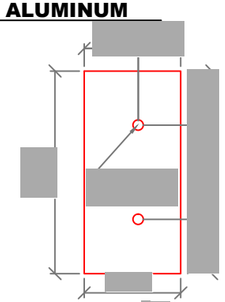
e1-PLATE - T6061 ALUMINUM
SCALE: NTS



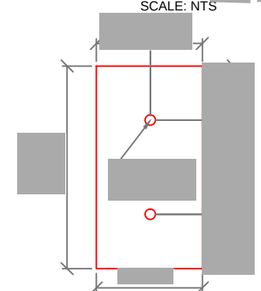
b1-TS T6061 ALUMINUM
SCALE: NTS



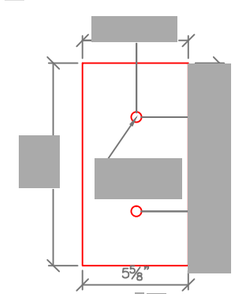
SECTION A-A
SCALE: NTS



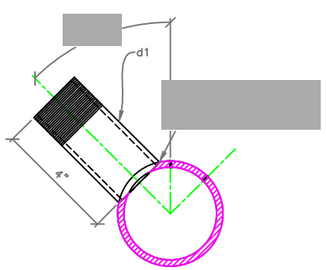
a4-PLATE - A36 STEEL
SCALE: NTS



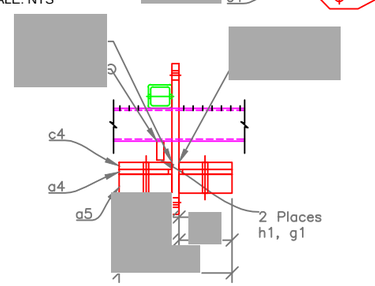
a5-PLATE - A36 STEEL
SCALE: NTS



c4-PLATE - T6061 ALUM.
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

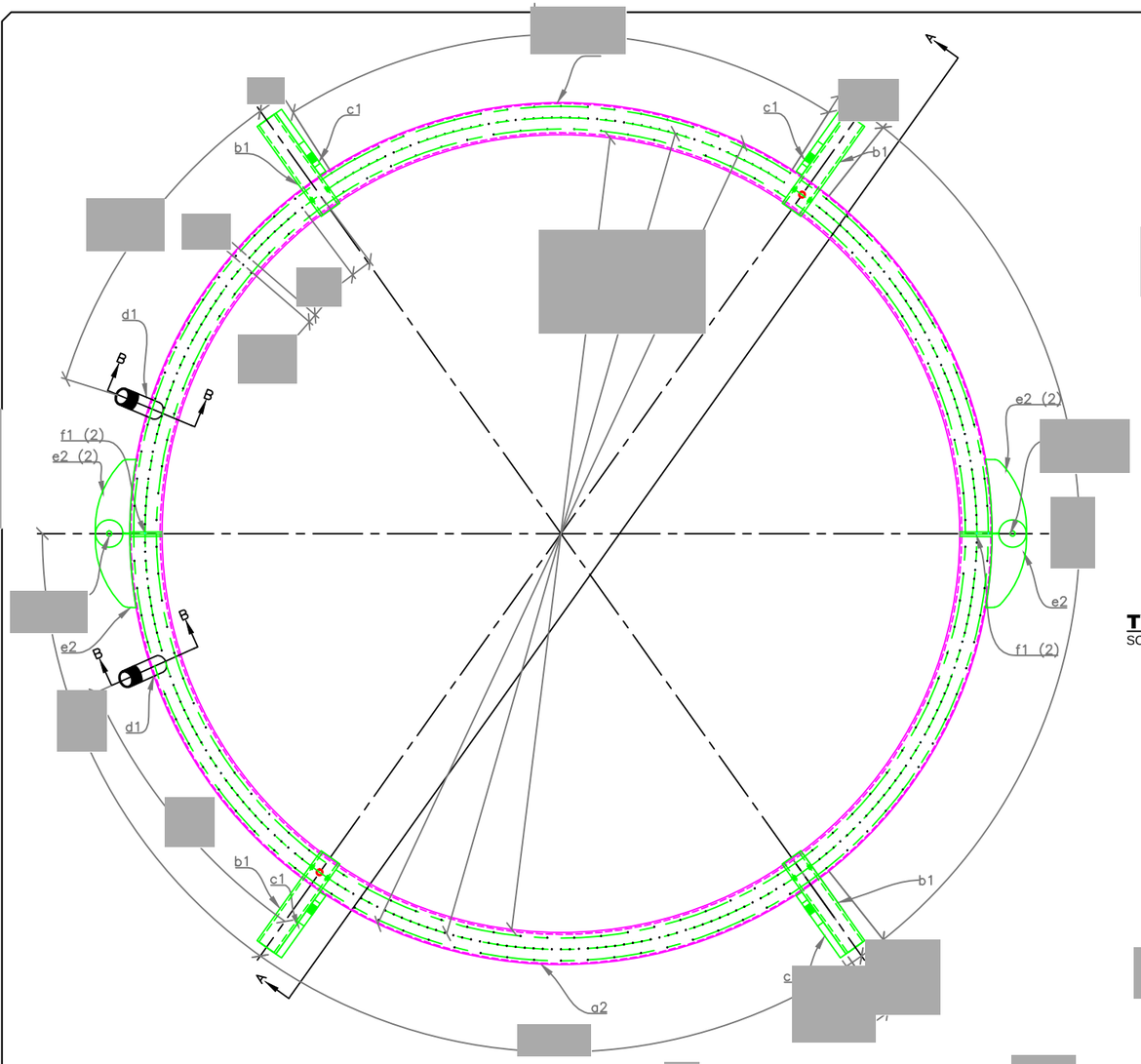
CONTRACT NUMBER: –

DATE: 5/19/13

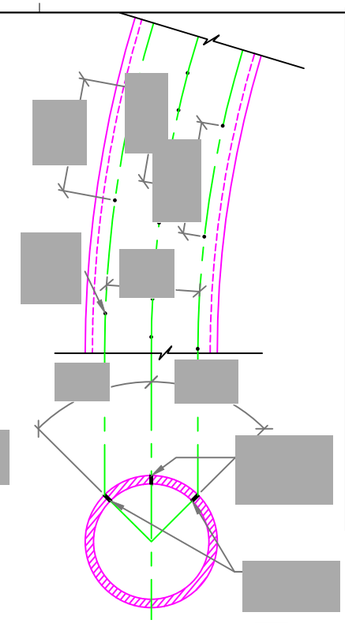
DRAWING NUMBER: 6UBCR

DOCUMENT TRACKING CODE: -

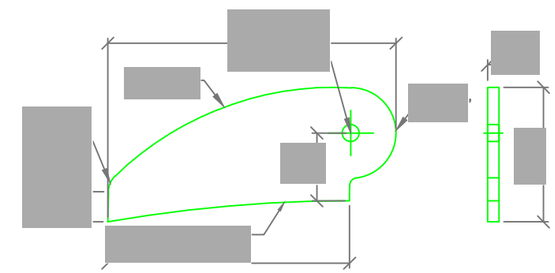
CHECKED BY: –
DRAFTED BY: –
CHECKED BY: –
DESIGNED BY: –
DESIGN SUPERVISOR: –



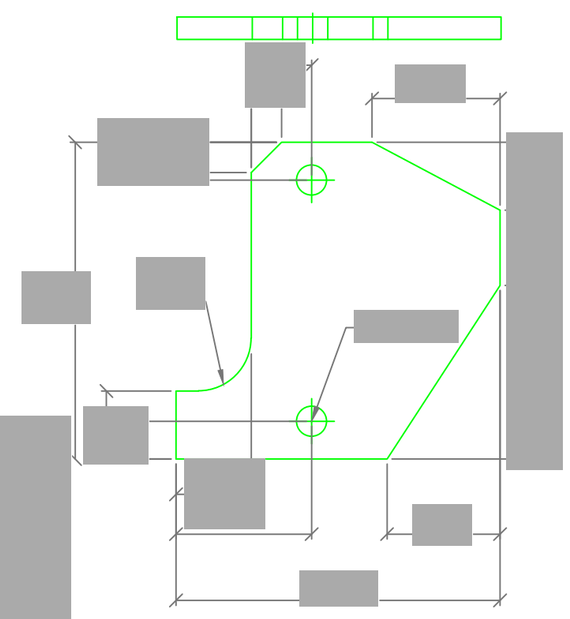
MK 2T - TOP BUBBLER RING FOR [redacted] PILES
SCALE: NTS



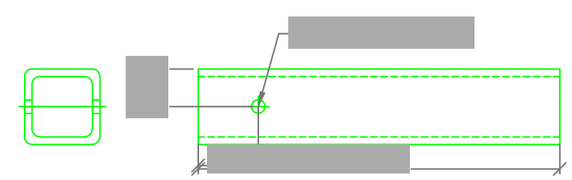
TYPICAL SECTION - [redacted] HOLE LAYOUT
SCALE: NTS



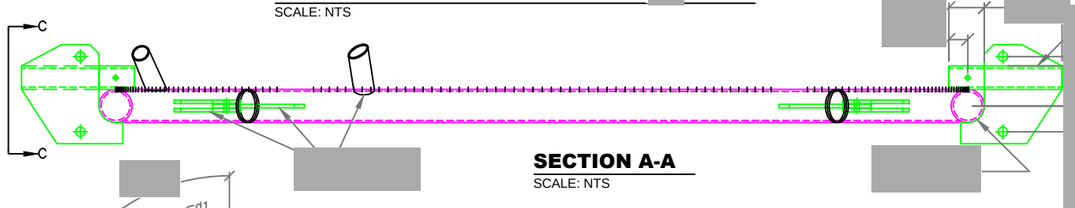
e2-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS



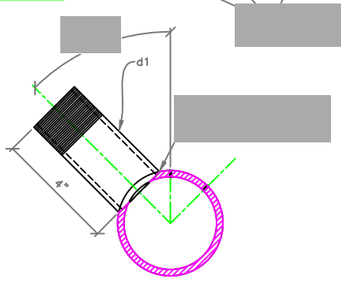
c1-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS



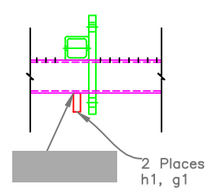
b1-TS [redacted] T6061 ALUMINUM
SCALE: NTS



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
[redacted]

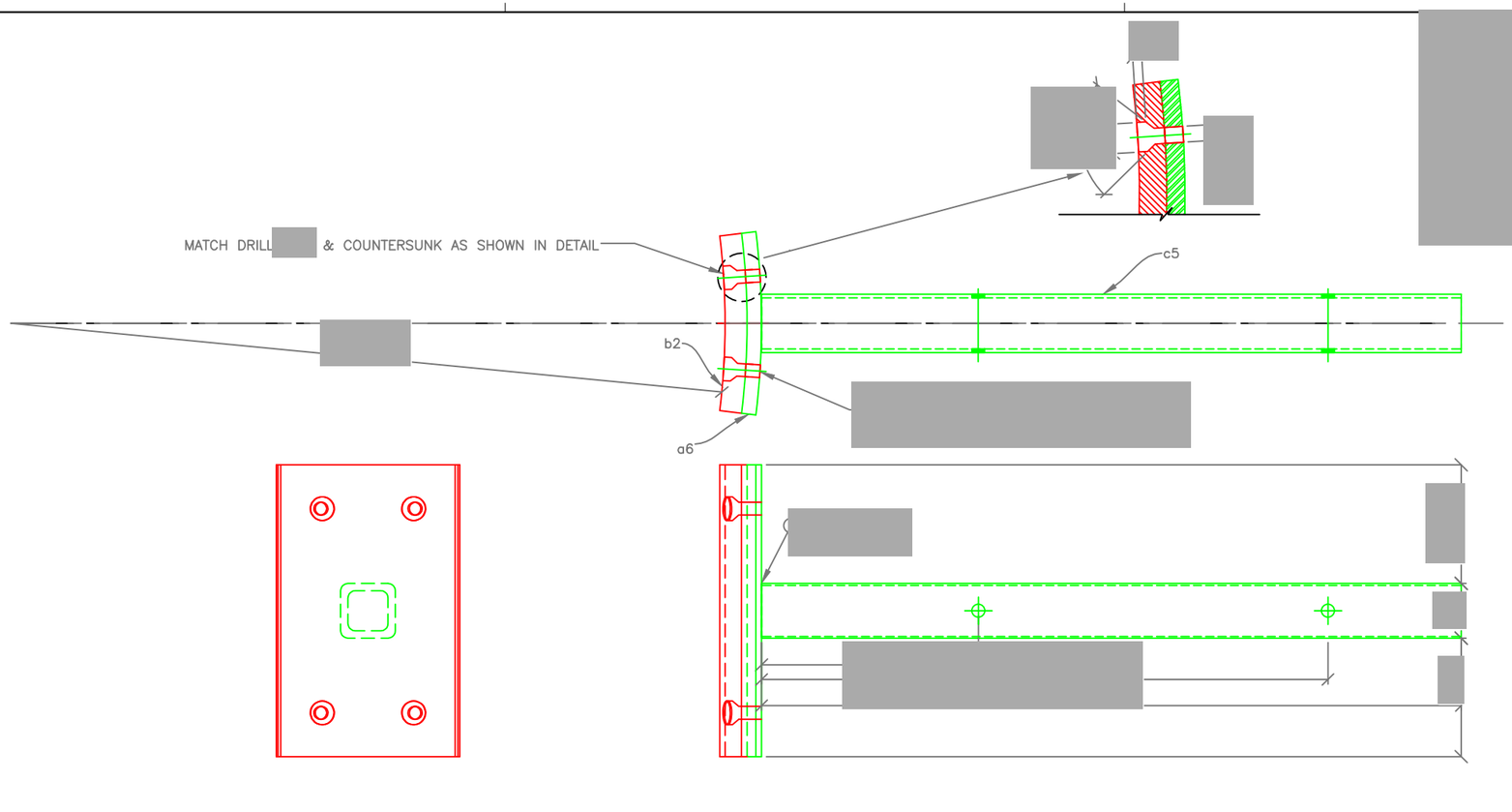
CONTRACT NUMBER: –

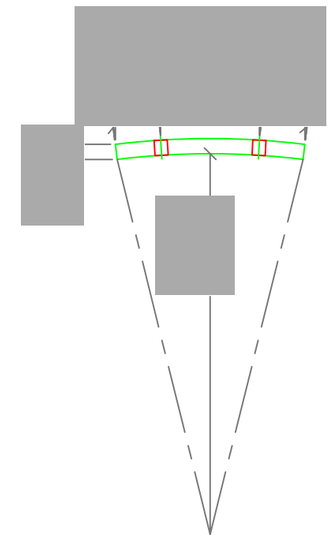
DATE: 5/19/13

DRAWING NUMBER: 7UBCR

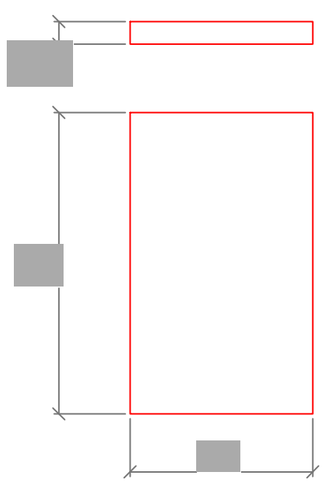
DOCUMENT TRACKING CODE: -

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

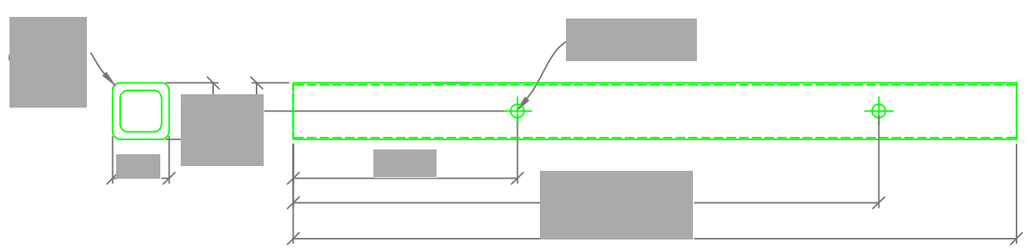




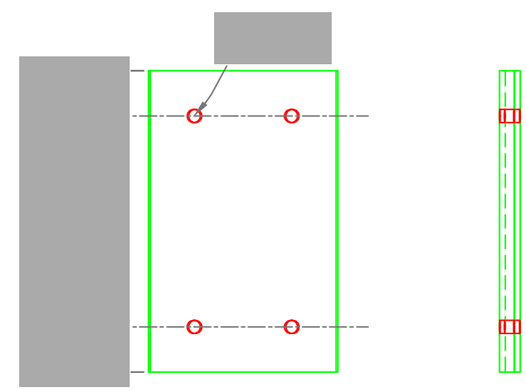
MK 3B - UHMW GUIDES FOR PILES
SCALE: NTS



b2 - UHMW
SCALE: NTS



c5 - SQ T6061 ALUMINUM
SCALE: NTS



a6 - PLATE T6061 ALUMINUM
SCALE: NTS

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

NEW YORK STATE THRUWAY AUTHORITY

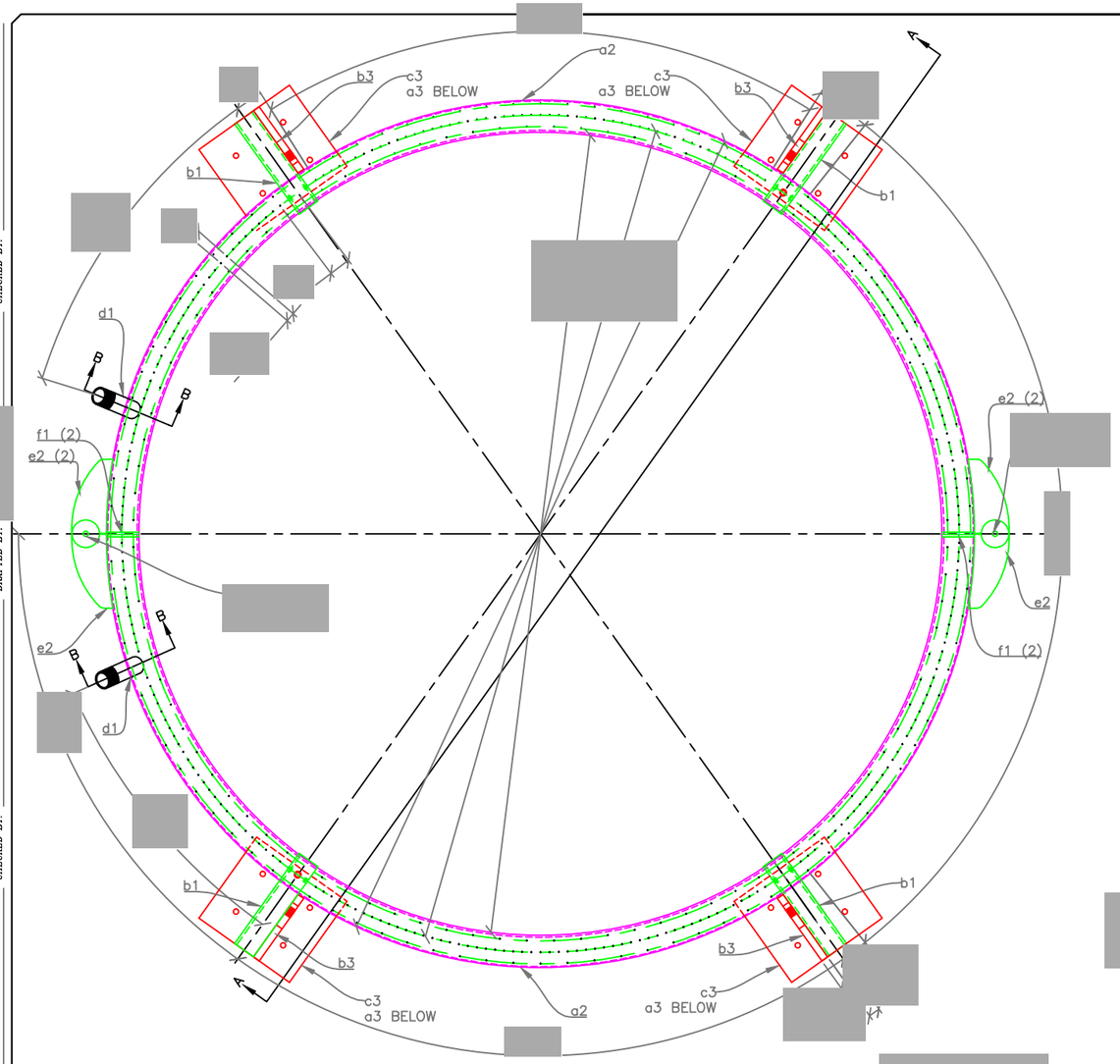
TAPPAN ZEE CONSTRUCTORS, LLC

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

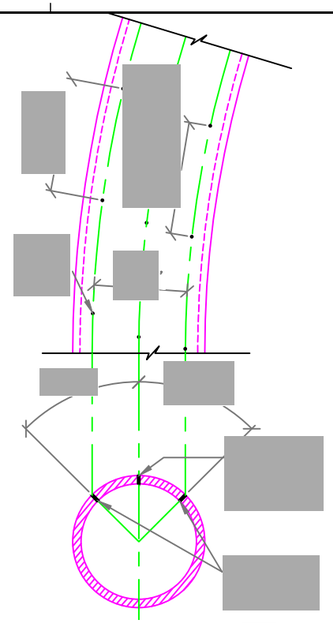
CONTRACT NUMBER: –
DATE: 5/19/13
DRAWING NUMBER: 8UBCR

DOCUMENT TRACKING CODE: -

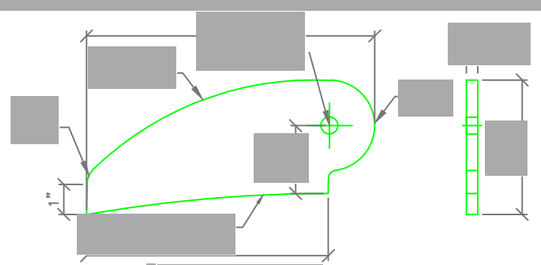
DESIGN SUPERVISOR: –
DESIGNED BY: –
CHECKED BY: –
DRAFTED BY: –
CHECKED BY: –



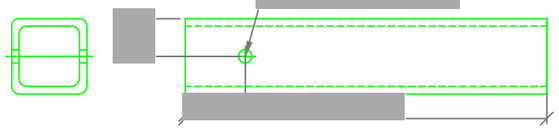
MK 2B - BOTTOM BUBBLER RING FOR [redacted] PILES
SCALE: NTS



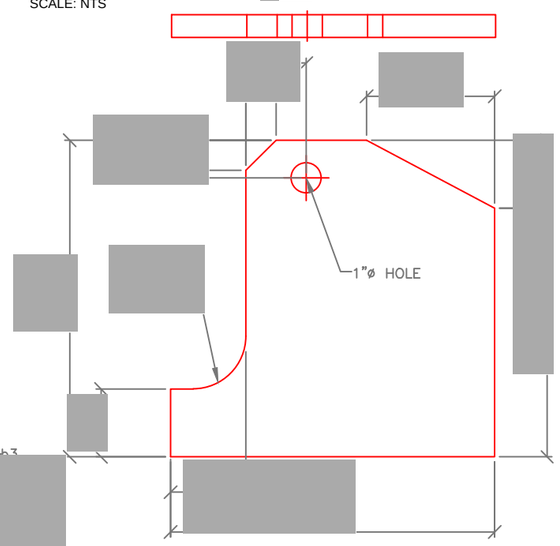
TYPICAL SECTION - [redacted] HOLE LAYOUT
SCALE: NTS



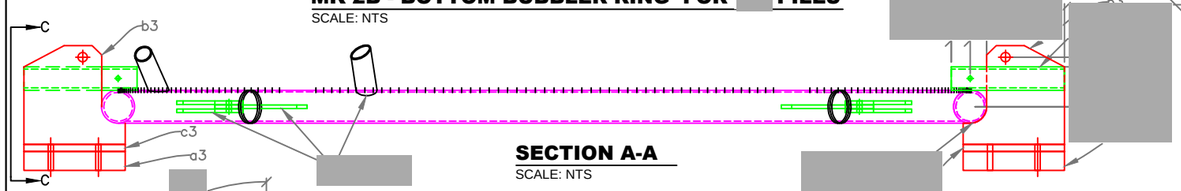
e2-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS



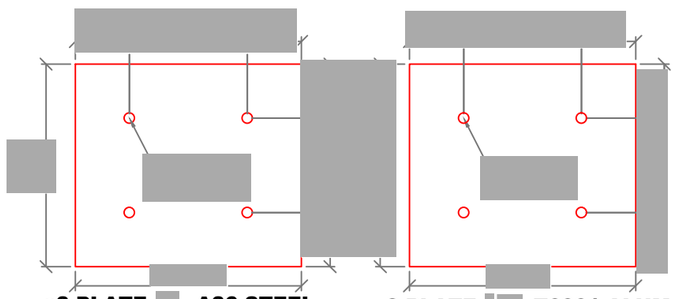
b1-TS [redacted] - T6061 ALUMINUM
SCALE: NTS



b3-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS

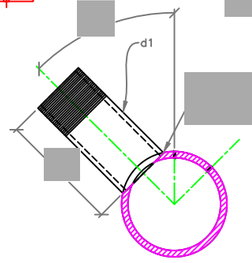


SECTION A-A
SCALE: NTS

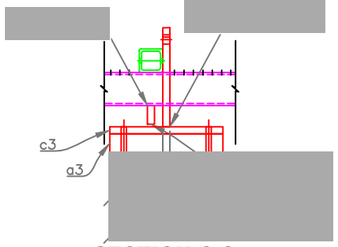


a3-PLATE [redacted] - A36 STEEL
SCALE: NTS

c3-PLATE [redacted] - T6061 ALUM.
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 [redacted]

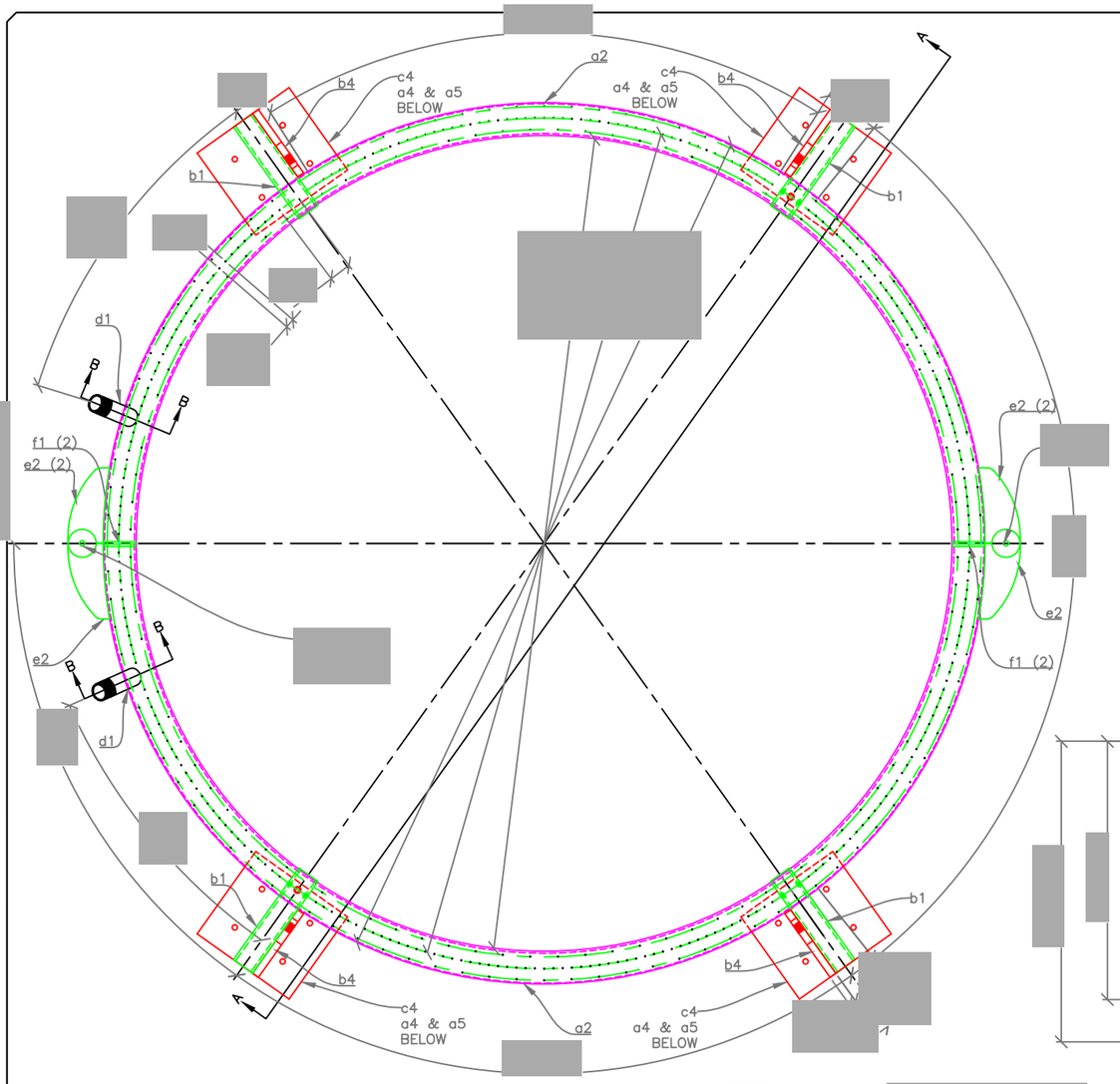
CONTRACT NUMBER: –

DATE: 5/19/13

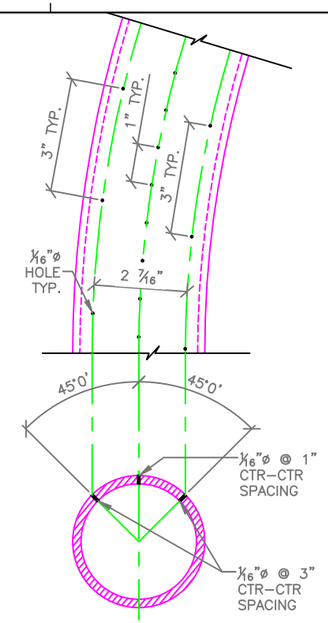
DRAWING NUMBER: 9UBCR

DOCUMENT TRACKING CODE: -

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



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

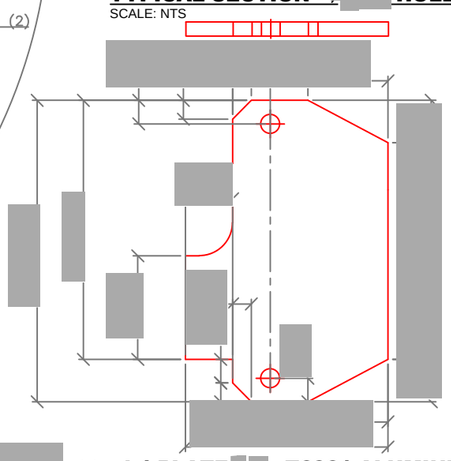


TYPICAL SECTION - [redacted] HOLE LAYOUT
SCALE: NTS

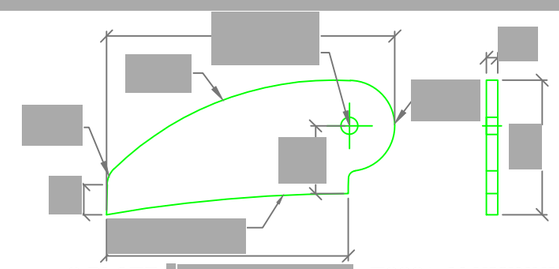
SECTION A-A
SCALE: NTS

SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS

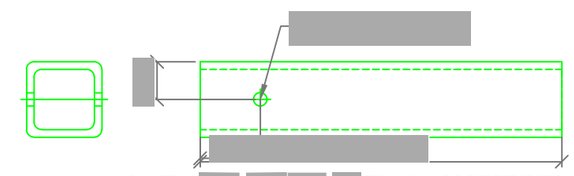
SECTION C-C
SCALE: NTS



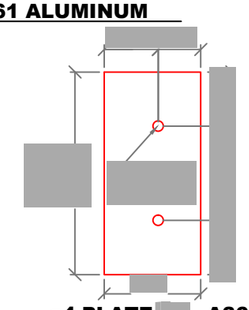
b4-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS



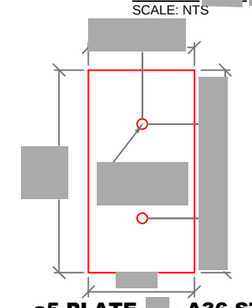
e2-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS



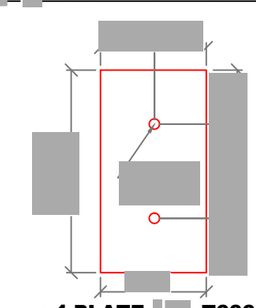
b1-TS [redacted] T6061 ALUMINUM
SCALE: NTS



a4-PLATE [redacted] - A36 STEEL
SCALE: NTS



a5-PLATE [redacted] - A36 STEEL
SCALE: NTS



c4-PLATE [redacted] - T6061 ALUM.
SCALE: NTS

REVISIONS			
DATE	DESCRIPTION	BY	SYM.

NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE
LOCATION OF PROJECT: NEW_YORK_STATE
TITLE OF DRAWING: UNCONFINED_BUBBLE CURTAIN_RINGS [redacted]

CONTRACT NUMBER: –
DATE: 5/19/13
DRAWING NUMBER: 10UBCR

DOCUMENT TRACKING CODE: -

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

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