# Description of Underwater Noise Attenuation System
# Design Unit 3
*for the*
# New NY Bridge Project

**Revision 1**
**January 29, 2014**

*Prepared by*
**Tappan Zee Constructors, LLC**
[redacted]

TAPPAN ZEE
CONSTRUCTORS, LLC

| Document History | | | |
|---|---|---|---|
| **Issue Date** | **Description** | **By** | **Revision** |
| 1/9/2014 | Issued to NYSDEC for permit condition 9. | [redacted] | 0 |
| 1/29/2014 | Addressed NYSTA comments | [redacted] | 1 |
| | | | |
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## 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 with a report titled *Description of Pile Load Test Program and Underwater Noise Attenuation System for the Tappan Zee Hudson River Crossing (PLT-NAS Description)* in July 2013. That report compared the NASs that were considered for possible adoption based upon the 2012 Pile Installation Demonstration Program (PIDP). The report also described the multi-tier bubble curtain which was selected for further testing. The *PLT-NAS Description* indicates the following criteria are being used to determine the effectiveness of the NAS:

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

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

Test pile installation monitoring results provide guidance on operational specifications of the underwater sound attenuation system monitoring, as well as the monitoring locations for production pile driving. The purpose of the present Report is to provide the results of the underwater noise monitoring of the installation of test piles for the Design Unit 3 (see Attachment 1) and based on those results, provide the design plans and anticipated operational specifications for the noise attenuation system for Design Unit 3 in accordance with the following NYSDEC Permit Conditions 8 and 9:

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

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

9. At least 30 days before starting installation of permanent piles [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 Test Piles

The Pile Load Test Program uses test piles in each of the 10 design units plus the Main Span (11 total design units), with the primary purpose to confirm pile load capacities. Design Unit 3 consists of [redacted] in piers 6 to 10. Test piles were installed with an IHC S-280 impact hammer. A summary of the impact pile driving for test piles at Design Unit 3 is provided in **Table 1**.

**Table 1. Summary of Impact Pile Driving for Test Piles at Design Unit 3**

| Test Pile | Pile Diameter | Impact Hammering Date |
|---|---|---|
| PLT-103P | [redacted] | 9/3/2013 |
| PLT-103 | | 9/4/2013 |
| PLT-104P | | 9/12/2013 |
| PLT-104 | | 9/18//2013 |
| PLT-105P | | 10/15/2013 |
| PLT-105 | | 10/15/2013 |

## 3.0 Unconfined Multi-tier Air Bubble Curtain NAS Design

Based on the NAS effectiveness determination in the *PLT-NAS Description*, the unconfined multi-tier bubble curtain was selected for further testing during test-pile installation. Refer to Attachment 2 for engineering details on the system.

### 3.1.1 NAS Components

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

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

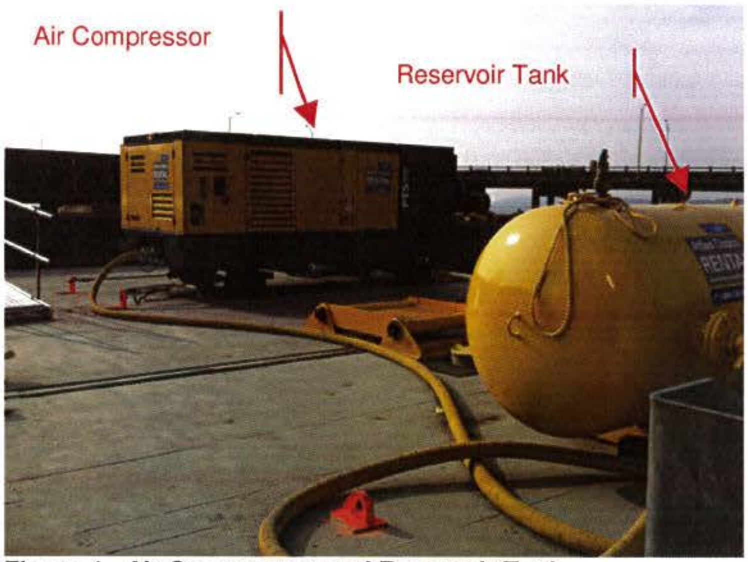



**Figure 1. Air Compressor and Reservoir Tank**

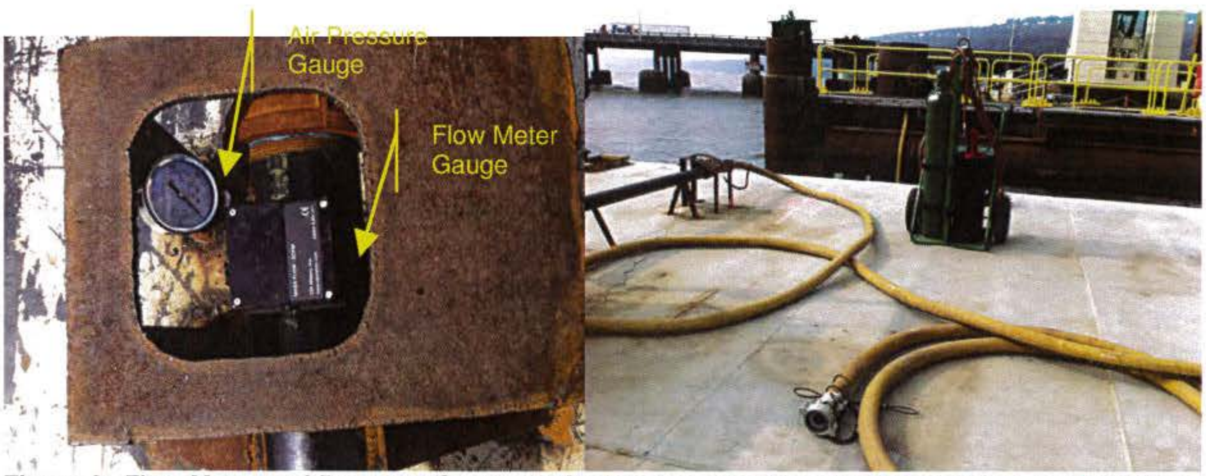



**Figure 2. Flow Meter and Pressure Gauge on Outlets from the Reservoir Tank to the Bubbler Ring**

### 3.1.2 NAS Deployment and Operation

The NAS deployment and operation proceeded as expected. After the piles were initially driven with the vibratory hammer, the bubble curtain ring was deployed with a crane and hung from the secondary template, using wire rope slings and shackles (Figure 3). The air compressor/reservoir tank pumped air into the ring (Figure 4), the impact hammer was lofted, the piles were tapped (i.e., a series of minimal energy strikes), and then driven to the required depth.

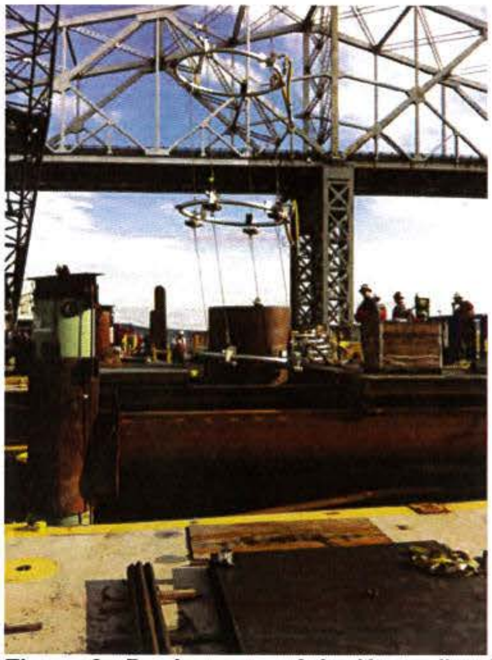


**Figure 3. Deployment of the Unconfined Multi-tier Bubble Curtain (One Ring Deployed)**

**Figure 4. Operation of the Multi-Tier Bubble Curtain (One Ring Deployed)**

## 4.0 Underwater Noise Monitoring During Test Pile Installation

### 4.1 Methods

Details of the equipment, the calibration of the equipment, the data collected, and the signal processing for underwater noise monitoring are included in the Underwater Noise Monitoring Plan. Details on the underwater noise monitoring during the installation of PLT 103P, PLT 103, PLT 104P, PLT 104, PLT 105P, and PLT 105 are provided in the Daily Memoranda for each day of pile driving (Attachment 1).

Figure 5 provides a typical barge and hydrophone arrangement for [redacted] piles. As illustrated in Figure 5, a real time Autonomous Multichannel Acoustic Recorder (AMAR-RT) and two Autonomous Multichannel Acoustic Recorders (AMARs) were generally placed at the distances of the noise level thresholds predicted in the NMFS BO (although locations varied based on conditions, such as vessel traffic and tides). The AMAR-RT was continuously monitored through out the pile driving process while data collected from the AMARs was downloaded following pile driving. The noise level thresholds predicted in the NMFS BO (April 2013) are as follows:

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

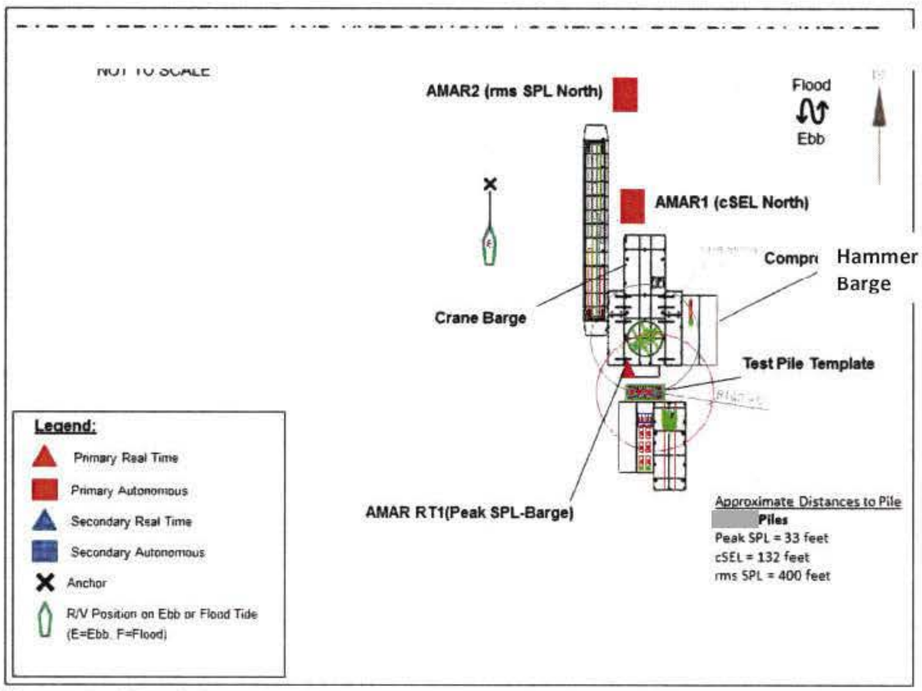



**Figure 5. Plan View of a Typical Test Pile Barge Arrangement and Hydrophone Locations [redacted]**

Test pile installation for the Design Unit 3 occurred during a variety of current conditions (ebb, flood, and slack tide). Hydrophones (AMARs) were placed to capture data to analyze variation in the performance of the NAS correlated with variation in the river current and barge placement. During the installation of PLT 103P the NAS was tested down-current and cross-current in a 0-1.1-knot flood to slack current. During the installation of PLT 103 NAS was tested up-current and cross-current in a 0.3-0.8-knot ebb current. PLT 104P tested the NAS up-current and cross-current in a 0-0.6-knot ebb to slack current. During the installation of PLT 104 the NAS was tested up-current in a 0-1.0-knot ebb to slack current. During the installation of the PLT 105P the NAS was tested up- and cross-current in a 0.3-1.0-knot ebb tide. During the installation of the PLT 105 the NAS was tested up- and cross-current in a 0.5-0.7-knot ebb tide. Table 2 provides a summary of the underwater noise monitoring equipment deployment and position relative to the current for the driving of the six test piles.

**Table 2. Equipment Deployment and Position Relative to Current for PLT 103P, PLT 103, PLT 104P, PLT 104, PLT 105P, and PLT 105**

| 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) |
|---|---|---|---|---|---|---|
| 9/3/2013 PLT 103P | AMAR-RT 11 | Peak SPL- Barge | Down-current | Flood to slack (0 – 0.8 knots) | 27 | 8 |
| | AMAR-221 | cSEL East | Cross-Current | | 199 | 9 |
| | AMAR-228 | rms SPL East | Cross-current | | 361 | 9 |
| 9/4/2013 PLT 103 | AMAR-RT 11 | Peak SPL-Barge | Up-Current | Ebb (0.3 – 0.8 knots) | 30 | 8 |
| | AMAR-228 | cSEL East | Cross-Current | | 125 | 8 |
| | AMAR-221 | rms SPL East | Cross Current | | 290 | 9 |
| 9/12/2013 PLT 104P | AMAR-RT 11 | Peak SPL- Barge | Up-Current | Ebb to slack (0 – 0.6 knots) | 32 | 10 |
| | AMAR-228 | cSEL 125 ft West | Cross-Current | | 201 | 9 |
| | AMAR-175 | rms SPL 500 ft West | Cross-Current | | 507 | 9 |
| 9/18/2013 PLT 104 | AMAR-RT 11 | Peak SPL- Barge | Up-Current | Ebb to slack (0 – 1.0 knots) | 32 | 9 |
| | AMAR 175 | cSEL North | Up-Current | | 184 | 9 |
| | AMAR-228 | rms SPL North | Up-Current | | 575 | 9 |
| 10/15/2013 PLT 105P | AMAR-RT 11 | Peak SPL Barge | Up-Current | Ebb (0.3 – 1.0 knots) | 33 | 13 |
| | AMAR-175 | cSEL North | Up-Current | | 163 | 13 |
| | AMAR-228 | rms SPL East | Cross-Current | | 468 | 12 |
| 10/15/2013 PLT 105 | AMAR-RT 11 | Peak SPL Barge | Up-Current | Ebb (0.5 – 0.7 knots) | 33 | 13 |
| | AMAR-175 | cSEL North | Up-Current | | 167 | 13 |
| | AMAR-228 | rms SPL East | Cross-Current | | 427 | 12 |

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

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

The tests for this design unit were informed by the tests for the previous Main Span and Design Unit 8 where air flow was varied throughout pile driving but never independently of other variables, such as impact hammer energies or tidal conditions. All tests were performed at a range of tidal conditions and hammer energies which could be expected during production pile driving. Table 3 provides the number of rings deployed and the NAS settings during the installation of the six test piles. During the installation of PLT 104P, the air flow and pressure unintentionally dropped to 0 psi during the first four minutes of pile driving (11:08-11:12), because the compressor outlet from the NAS was closed.

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

| Date/ Test Pile No. | Water Depth (ft) | Number of Rings | Air Flow (cfm) per Bubbler Ring | Air Pressure (psi) |
|---|---|---|---|---|
| 9/3/2013 PLT 103P | 8 | 1 | 1100-2000 | 35-80 |
| 9/4/2013 PLT 103 | 8 | 1 | 900-2150 | 34-80 |
| 9/12/201 PLT 104P | 9 | 1 | 0-1600 | 0-135 |
| 9/18/2013 PLT 104 | 9 | 1 | 1300-1425 | 55-57 |
| 10/15/2013 PLT 105P | 13 | 2 | 1700-1800 | 65 |
| 10/15/2013 PLT 105 | 13 | 2 | 1700-1800 | 65 |

## 4.2 Results

### 4.2.1 NMFS Physiological and Behavioral Thresholds

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

Table 4 provides a summary of the underwater sound levels measured at each recorder during the test pile installation. Table 5 provides the diameter of the sound level isopleths that serve as the NMFS physiological and behavioral thresholds. **These results show that when the NAS was operational, the diameter of the 206 dB re 1 μPa peak SPL did not exceed NMFS requirement of 40 ft for [redacted] piles at Design Unit 3.** The largest diameter of the 206 dB re 1 μPa peak SPL isopleth was 26 ft, which is similar to the 206 dB re 1 μPa peak SPL for the NASs tested during the 2012 PIDP. Specifically, during the 2012 PIDP the diameters of the 206 dB re 1 μPa peak SPL isopleth were 15 – 40 ft for [redacted] piles (JASCO 2012)[2]. Furthermore, the estimated diameter of the isopleth at the end of installation of test piles that corresponded to 187 dB re 1 $\mu Pa^2$-s cSEL never exceeded 205ft. The river width is approximately 15,000 ft; therefore a fish movement corridor of more than one mile [5,280 ft], which was continuous for more than 1,500 ft, was maintained throughout pile driving, in accordance with New York State Department of Environmental Conservation Permit Condition 14.

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

**Table 4. Summary of the Measured Sound Levels at Each Recorder During the PLT 103P, PLT 103, PLT104P, PLT 104, PLT 105P, and PLT 105**

| Date Test Pile No. | Location* | Max. peak SPL (dB re 1 µPa) | cSEL (dB re 1 µPa$^2$-s)** |
|---|---|---|---|
| 9/3/2013 PLT 103P | Peak SPL- Barge | 195 | 198 |
| | cSEL East | 179 | 184 |
| | rms SPL East | 168 | 173 |
| 9/4/2013 PLT 103 | Peak SPL- Barge | 193 | 194 |
| | cSEL East | 170 | 177 |
| | rms SPL East | 166 | 172 |
| 9/12/2013 PLT 104P | Peak SPL- Barge | 204 | 201 |
| | cSEL 125 ft West | 180 | 175 |
| | rms SPL 500 ft West | 165 | 165 |
| 9/18/2013 PLT 104 | Peak SPL- Barge | 200 | 198 |
| | cSEL North | 173 | 177 |
| | rms SPL North | 157 | 162 |
| 10/15/2013 PLT105P | Peak SPL Barge | 188 | 197 |
| | cSEL North | 170 | 180 |
| | rms SPL East | 162 | 168 |
| 10/15/2013 PLT105 | Peak SPL Barge | 185 | 196 |
| | cSEL North | 171 | 180 |
| | rms SPL East | 165 | 170 |

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

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

**At the completion of pile driving.

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

| Measurement | | PLT 103P | PLT 103 | PLT 104P | PLT 104 | PLT 105P | PLT 105 |
|---|---|---|---|---|---|---|---|
| Pile Installation Duration (hh:mm)* | | 00:45 | ~00:35** | 00:27 | 00:26 | ~00:40** | 00:20 |
| Approximate Diameter (ft) of Isopleth | 206 dB re 1 µPa peak SPL | 8 | 6 | 26 | 19 | 10 | <6 |
| | 187 dB re 1 µPa$^2$-s cSEL | 204 | 110 | 181 | 156 | 170 | 164 |
| | 150 dB re 1 µPa rms SPL | 616 | 378 | 424 | 386 | 518 | 584 |

* Net pile driving times are rounded to the nearest minute.
** Pile installation duration is an approximation based on the number of strikes recorded in the GZA field log and an assumption of 57 strikes per minute, because the hammer read-out malfunctioned.

### 4.2.2 NAS Performance

The NAS was tested in flood, ebb, and slack currents with hydrophones located in up-current, down-current, and cross current positions (Table 2). Current speed ranged from 0 to 1.6 knots. Air flow settings ranged from air pressures of 0 to 135 psi and air flows of 0 to 2000 cfm.

For PLT 103P, the NAS air pressure was 50–80 psi (1700–2000 cfm) during the first phase of installation and 35–45 psi (1100–1600 cfm) during the second phase There was no observable effect on the measured sound levels from the change in air pressure or the change in current.

For PLT 103, the NAS air pressure was 70–80 psi (1300–2150 cfm) during most of the pile installation, except a 2.5 min period from 16:03–16:05:30 when pressure fell to 34 psi when the valve from a compressor was not open. The measured sound levels at the closest measurement location increased by 3–7 dB during this period, but sound levels at the other two locations did not show an increase.

During the first four minutes of PLT 104P, air pressure at the NAS dropped from 135 to 0 psi (1500–0 cfm) because the valve from the air compressor to the air-tank was closed. Pile driving stopped and resumed with proper NAS operation at 11:12. Air pressure ranged between 55 and 70 psi (1400-1600 cfm) for the remainder of the pile driving. Once the compressor valve was opened and with resumption of air pressure sound levels at all three recorders decreased approximately 10 dB at every measurement location.

For PLT 104 hammer energy and air pressure remained constant, at approximately 55 psi, but the currents dropped from 0.6 knots to slack current. However, there was no observable effect on the measured sound levels from the change in current.

Finally, during the installation of PLT 105, hammer energy and NAS air pressure and airflow were constant at approximately 65 psi. Pile driving occurred mid-way between slack and ebb tides, with currents less than 0.7 knots and concluded near the end of the end tide, when the current reduced to 0.1 knots. However, in this instance there was no observable effect on the measured sound.

Although some variation in sound propagation was noted during the testing under air pressure settings, tidal conditions, and measurement locations, the NMFS and NYSDEC required thresholds were not exceeded under normal operating conditions. The only exception was when the compressor outlet was unintentionally closed for a brief period (approximately 4 minutes) during the installation of PLT 104P. The regression of the sound levels for approximately 30 seconds when the pressure dropped to 0 psi, indicates that the estimated diameter of the 206 dB re 1 μPa peak SPL isopleth was 48 ft, which exceeds the NMFS criterion of a diameter of 40 ft [redacted]

## 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] r to minimize to the maximum extent practicable the effects of underwater sound upon fishes in the Hudson River." The *PLT-NAS Description* concludes that the most effective system is the one that will be capable of attenuating noise to achieve the distance thresholds required by NMFS in the BO and that can be safely deployed and retrieved repeatedly during production pile driving without affecting pile driving requirements and project schedule.

Results of test pile installation indicate that the unconfined multi-tier bubble curtain with bubble rings spaced a maximum of ten feet vertically is effective in minimizing noise in order to meet the NMFS and NYSDEC requirements. Not only did the NAS meet the requirements in full ebb and flood tides and for various NAS settings, underwater sound was reduced beyond NMFS and NYSDEC requirements. Results indicate that the largest estimated width of the 206 dB re 1μPa peak SPL isopleth was measured at 26 ft, as compared to the 40 ft predicted by the NMFS BO. These results indicate that the size of the 206 dB re 1 μPa isopleth measured for the [redacted] in 10-15 ft of water was smaller than the 206 dB re 1 μPa isopleths measured during the 2012 PIDP. Furthermore, the diameter of the 187 dB re 1 $\mu Pa^2$-s cSEL isopleth at the end of installation of each pile was never estimated to be more than 204 ft. Therefore, a corridor was maintained where sound levels were less than 187 dB re 1$\mu Pa^2$·s cSEL. The total length of the corridor was at least one mile (and was continuous for 1,500 feet) across the Hudson River, running east to west.

## 5.0 NAS Design Plan and Operational Specifications

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

During production pile driving for Design Unit 3, the unconfined multi-tier bubble curtain will be deployed and retrieved in a similar manner to the PLT 103P, PLT 103, PLT 104P, PLT 104, PLT 105, and PLT 105P pile installations. Based on dredging and armoring, the river bottom at Design Unit 3 will be approximately -11 feet at mean lower low water (MLLW). Bubbler rings and compressors will be deployed for each pile, so that vertical spacing in the water column is a maximum of 10 feet or less at mean higher high water (MHHW). That is, the NAS will consist of two bubble rings if the water depth greater than 10 feet. If the water depth is less than 10 feet, only one bubble ring will be used.

The NAS system contains three valves at the:

1. air compressor outlet to the reservoir tank (Figure 6),
2. reservoir tank inlet (Figure 7),
3. reservoir tank outlet (Figure 8) to the bubbler ring.

Prior to impact pile driving, the compressor will be turned on and the valves will be open such that air will be supplied to the bubbler ring. 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 9).

The following will be checked for each of the piles at each pier within Design Unit 3 (as outlined in the Construction Work Plan):

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


**Figure 6. Valve at the Air Compressor Outlet to the Reservoir Tank**

**Figure 7. Valve at the Reservoir Tank Inlet**


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

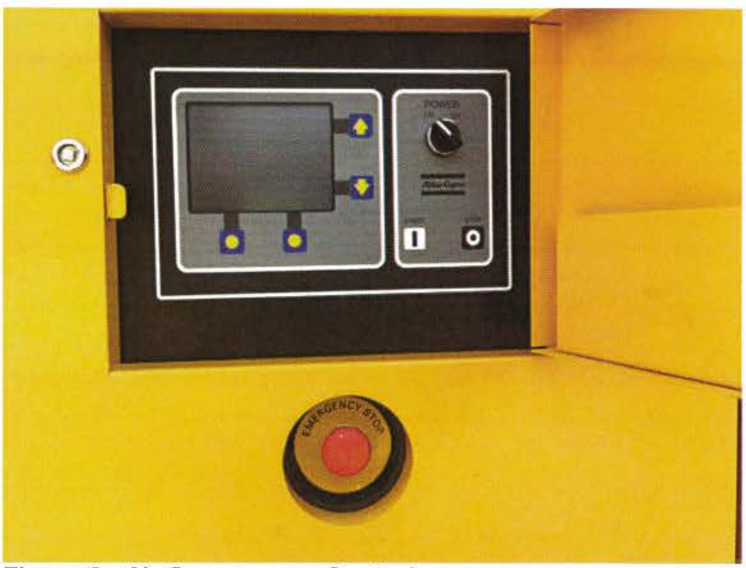


**Figure 9. Air Compressor Controls**

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

# Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile PLT-103P Installation

**Daily Memorandum for 03 September 2013**

*Submitted to:*

[redacted]

*Authors:*


[redacted]

JASCO Applied Sciences

[redacted]


03 January 2014

P001206-001

# 1. Summary

## 1.1. Pile Location and Monitoring Summary

PLT-103P is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 03 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 monitor sound levels during test pile installation (Figure 1, and Table 2). Pile driving occurred between 09:19–10:58 EDT; full flood tide was predicted at 09:17 EDT. Pile driving occurred over two periods, 09:20–09:40 and 10:35–10:55. Breaks often occurred during test pile installation and vary between test piles. The breaks were generally due to transfer of pile equipment and marking test piles during installation.

Table 1. Summary of PLT-103P activities, 03 September 2013.

| | |
|---|---|
| Date: | 03 September 2013 |
| ***Pile-Driving Activity*** | |
| Test pile identifier: | PLT-103P |
| Pile diameter: | [redacted] |
| Water depth: | 8 ft |
| Hammer type: | Impact (IHC S-280) |
| Total hammer strikes: | 2456 |
| Total penetration: | |
| Net duration of pile driving (hh:mm:ss): | 00:45:08 |
| Maximum single strike energy: | 127 thousand foot-pounds (kip-ft), (172 kJ) |
| Total energy transferred: | 296,511 kip-ft (402 MJ) |
| ***Noise Attenuation System (NAS)*** | |
| Single-tier unconfined bubble curtain airflow rate: | 1100–2000 cubic feet per minute (cfm), 35–80 psi |
| River conditions during pile driving: | Flood to slack tide,<br>Predicted: 0–1.1 knots (0–0.6 meters per second [m/s], depth dependent; Table 6 and Figure 5)<br>Measured: 0–0.8 knots (0–0.4 m/s, Figure 5) |

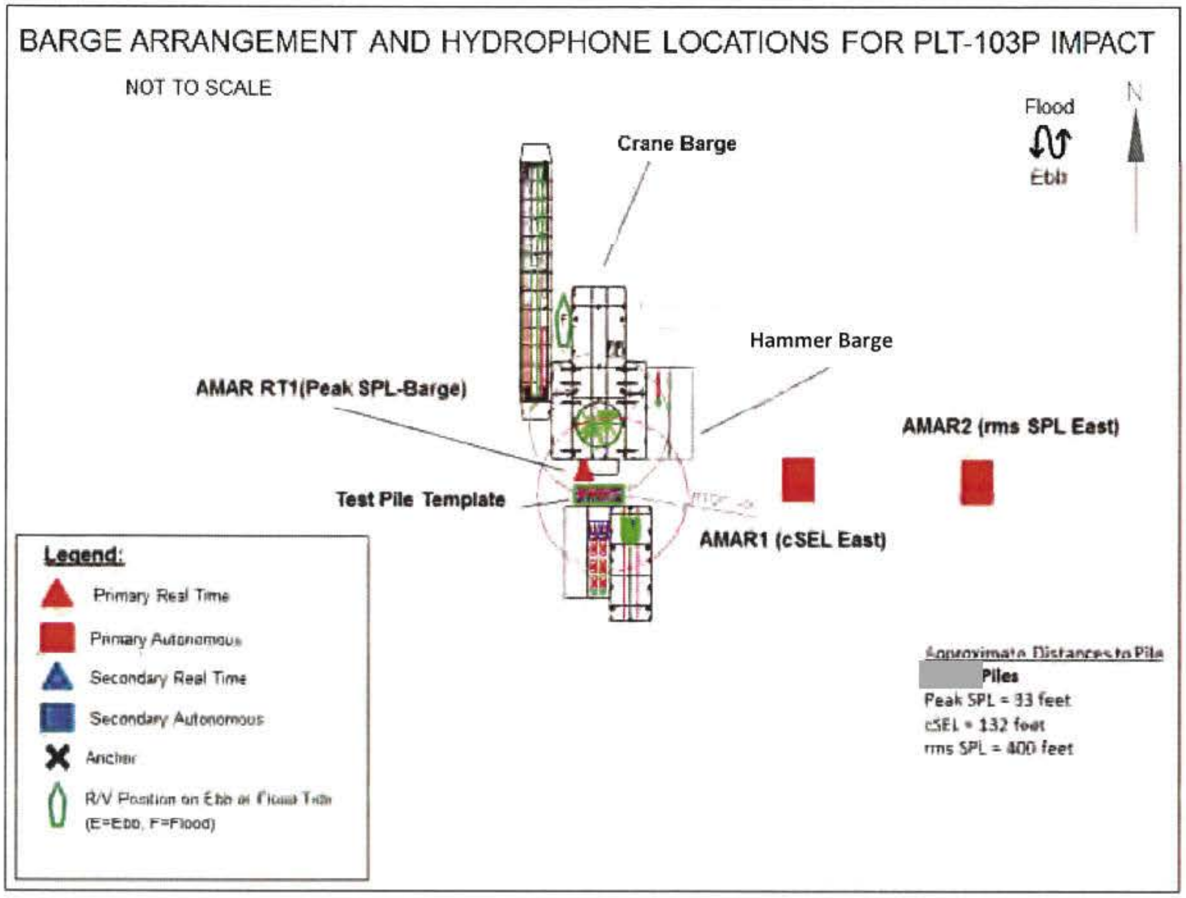



Figure 1. Plan view of pile and barge layout, 03 September 2013, PLT-103P.

Table 2 provides the sound levels measured at each recorder. The maximum sound levels were measured at the Peak SPL Barge location, which was closest to the pile driving. Plots of the measured values, frequency distributions of 1/3 octave single-strike sound exposure level (SELss), and sound level statistics for the distribution of the measured data are presented in Appendix A.

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 re1 µPa) | cSEL (dB re 1 $\mu Pa^2 \cdot s$)* |
|---|---|---|---|---|---|
| Peak SPL Barge (down-current) | AMAR-RT-11 | 27 | 8 | 195 | 198 |
| cSEL East (cross current) | AMAR-221 | 199 | 9 | 179 | 184 |
| rms SPL East (cross current) | AMAR-228 | 361 | 9 | 168 | 173 |

*Calculated by multiplying the average SELss by the number of strikes reported by the pile driving contractor, representing the total energy at the end of pile driving.

## 1.2. NMFS Physiological and Behavioral Thresholds

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

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was approximately 8 ft, and did not exceed NMFS criteria of a diameter of 40 ft for [redacted] piles. The diameter of the 187 dB re 1 $\mu Pa^2 \cdot s$ cumulative sound exposure level (cSEL) isopleth was estimated to be 204 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 204 ft for most of the pile driving operation. 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 diameter for the NMFS physiological and behavioral thresholds.

| Criteria | Estimated Mean Diameter (ft) |
|---|---|
| 206 dB re 1 µPa peak SPL | 8 |
| 187 dB re 1 $\mu Pa^2 \cdot s$ cSEL | 204* |
| 150 dB re 1 µPa rms SPL (1 s integration time) | 616 |

* At the end of pile driving

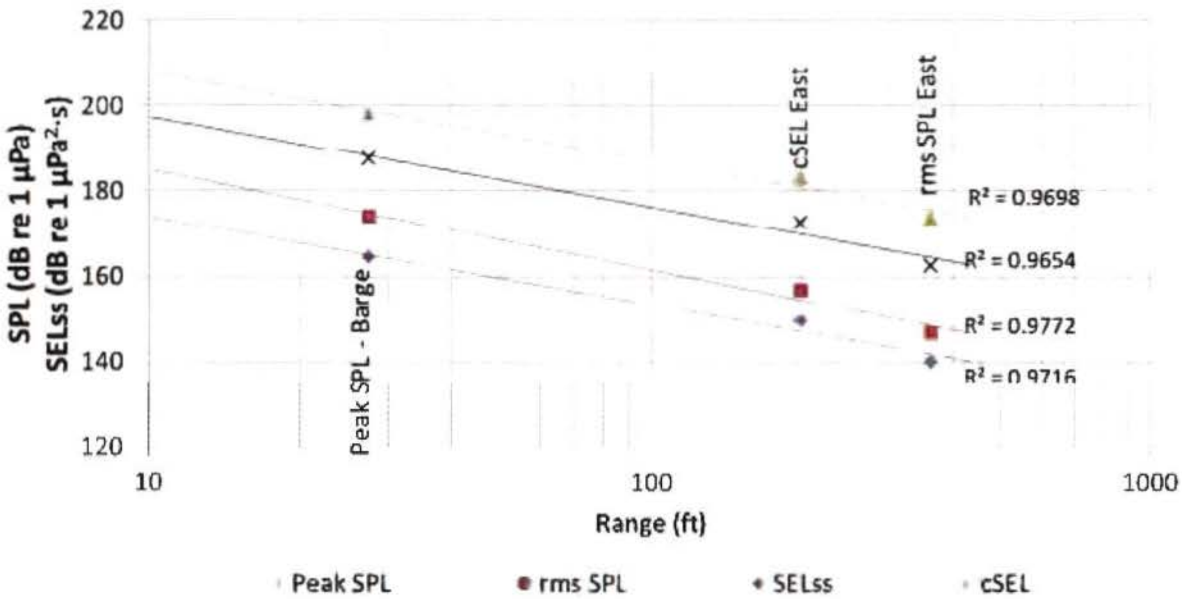



Figure 2. Regression based on mean values of the SELss, peak SPL, cSEL, and rms SPL from each recorder from pile driving of Test Pile PLT-103P, 03 September 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents the total sound energy measured, and reflects the cumulative exposure at the end of the pile driving.

## 1.3. Observations

The hammer energy was nearly constant at 120±8 kip-ft (Figure 4) throughout the pile driving at PLT-103P. Pile driving occurred over two periods, 09:20–09:40 and 10:35–10:55. The current was an average of 0.5 knots during the first period and slack during the second period (Figure 5). Both autonomous recorders were cross-current (Figure 1). The NAS air pressure was 50–80 psi (1700–2000 cfm) during the first period and 35–45 psi (1100–1600 cfm) during the second period (Table 5). There was no observable effect on the measured sound levels from the change in air pressure or the change in current (Figure 3).

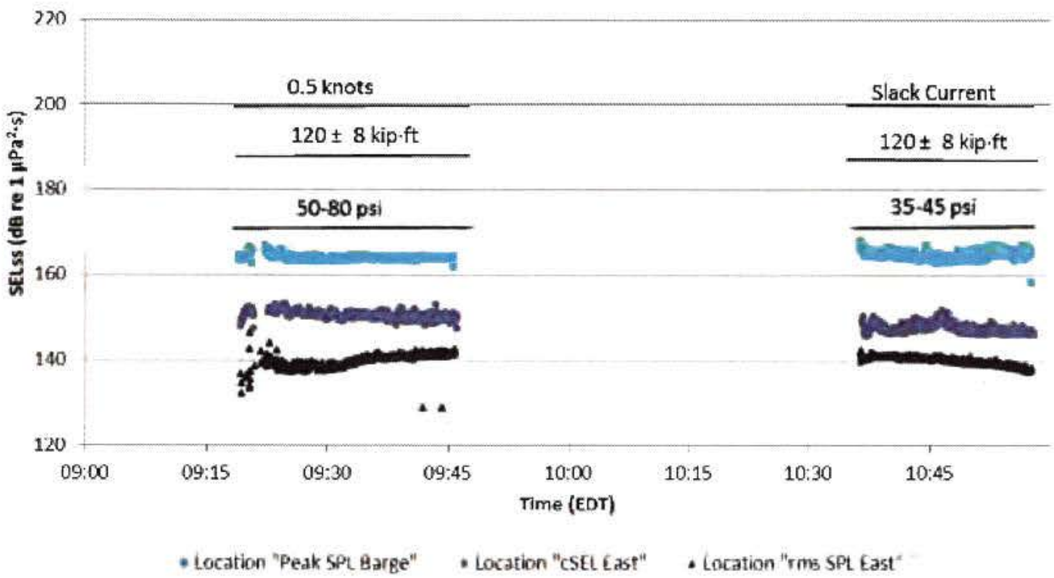



Figure 3. Comparison of SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

# 2. Activity Logs

Table 4 provides activities for 03 September 2013.

## 2.1. Log of JASCO and Construction Activities

Table 4. JASCO and construction activities for Test Pile PLT-103P, 03 September 2013.

| Time (EDT) | Activity |
|---|---|
| 07:45 | Arrive at dock and leave for Hudson Harbor |
| 08:20 | Arrive Hudson Harbor and transit to barge |
| 08:30 | Arrive at barge and prepare recorders |
| 08:55 | AMAR-RT-11 deployed and recording. |
| 09:05 | Begin deploying AMAR-221 |
| 09:15 | Begin deploying AMAR-228 |
| 09:19 | Start pile driving |
| 10:58 | Pile driving complete |
| 11:38 | Begin retrieving all recorders |
| 13:00 | All work complete. |

## 2.2. Pile Driving Logs

### 2.2.1. NAS

Noise Attenuation System (NAS) Used: Single-tier unconfined bubble curtain.

NAS Settings: 1100–2000 cfm, 35–80 psi

Table 5. NAS setting pile driving at PLT-103P, 03 September 2013.

| Time (EDT) | Volume/min (cfm) | Pressure (psi) |
|---|---|---|
| 09:19–09:46 | 1700–2000 | 50–80 |
| 10:47–10:58 | 1100–1600 | 35–45 |

### 2.2.2. Impact Hammering Log

Total energy: 296,511 kip-ft (402 MJ)

Total number of strikes: 2456

Maximum per-strike energy: 127 kip-ft (172 kJ)

Net pile driving duration (hh:mm:ss): 00:45:08

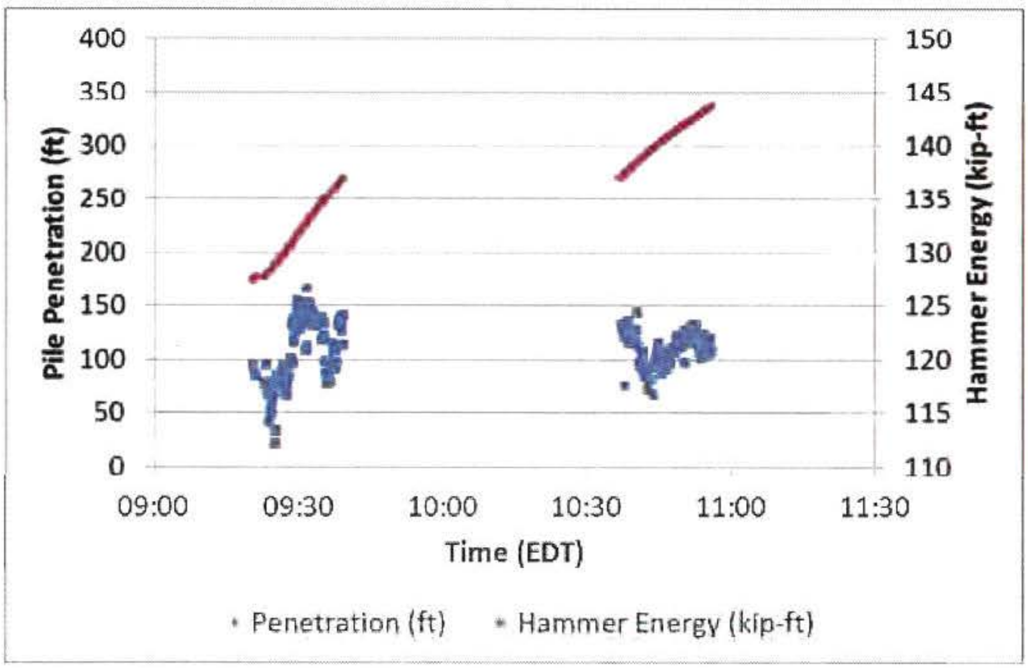



Figure 4. Hammer energy (kip-ft) and pile penetration (ft) during pile driving of PLT-103P, 03 September 2013.

# 3. Weather and River Conditions

Table 6 provides the predicted currents at the project site on 03 September 2013. Figure 5 provides the Acoustic Doppler Current Profiler (ADCP)-measured currents. Figure 6 provides the speed of sound in water, based on salinity and temperature measured using the CTD.

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

| | |
|---|---|
| Weather conditions: | Cloudy, calm, wind ~3 kts from south. |
| Full ebb current: | 15:23 (1.5 kts max) |
| Slack current: | 11:45, EDT |
| Full flood current: | 09:17 (1.1 kts max) |

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=

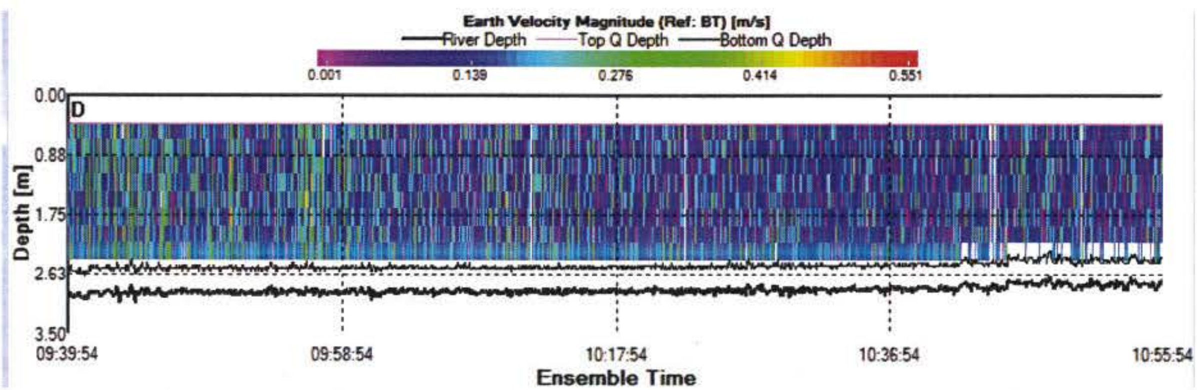



Figure 5. ADCP data from 03 September 2013 at location Peak SPL Barge, times are in EDT

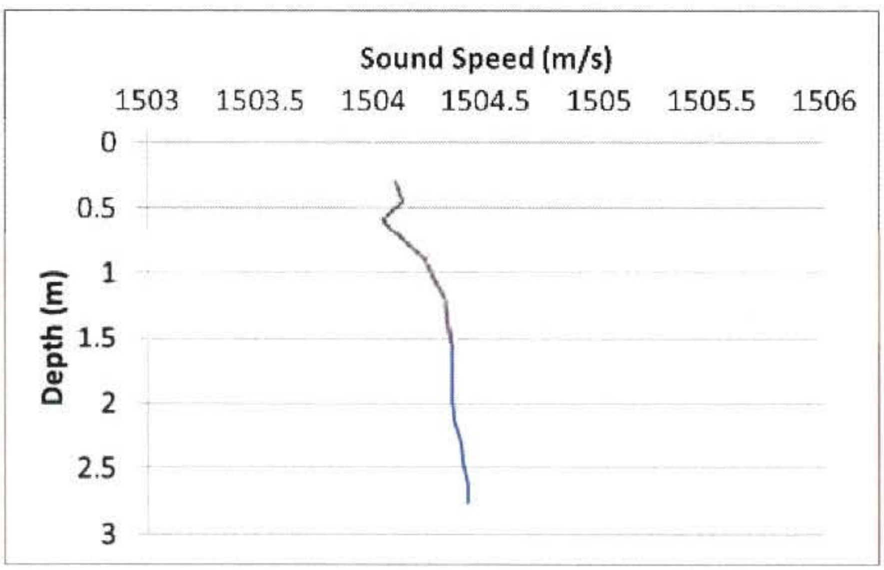



Figure 6. CTD cast performed on the Alpine Vessel at 41.071466° N, 73.914640° W.

# 4. Monitoring Equipment

## 4.1. Real-time Monitoring Equipment

Table 7 provides information on the real-time monitoring equipment used on 03 September 2013. Table 8 provides location information on the real-time recorders

Table 7. Real-time monitoring equipment for Test Pile PLT-103P, 03 September 2013.

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

Table 8. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 03 Sep 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time | Water Depth (ft) | Distance to Pile (ft) |
|---|---|---|---|---|---|---|
| Peak SPL Barge | AMAR-RT-11 | 41.071870 | 73.915200 | 08:55 | 8 | 27 |

## 4.2. Autonomous Monitoring Equipment

Table 9 provides information on the autonomous monitoring equipment used on 03 September 2013. Table 10 provides the locations of the autonomous recorders.

Table 9. Autonomous monitoring equipment Test Pile PLT-103P, 03 September 2013.

| **Acoustic Data Logger** | | **Units deployed** |
|---|---|---|
| Model: | AMAR G3 (JASCO Applied Sciences) | 2 |
| *SpectroPlotter* version: | 6.0.1 | 2 |
| **Hydrophone** | | |
| Model: | M8E-51-0dB (GTI) | 2 |
| AMAR-221 sensitivity: | -199.8 dB re 1 V/µPa | 1 |
| AMAR-228 sensitivity: | -199.7 dB re 1 V/µPa | 1 |

Table 10. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations 03 September 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time (EDT) | Water depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| cSEL East (cross current) | AMAR-221 | 41.071466 | 73.914640 | 09:05 | 9 | 199 |
| rms SPL East (cross current) | AMAR-228 | 41.071424 | 73.913986 | 09:15 | 9 | 361 |

# Appendix A. Pile Driving Plots

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

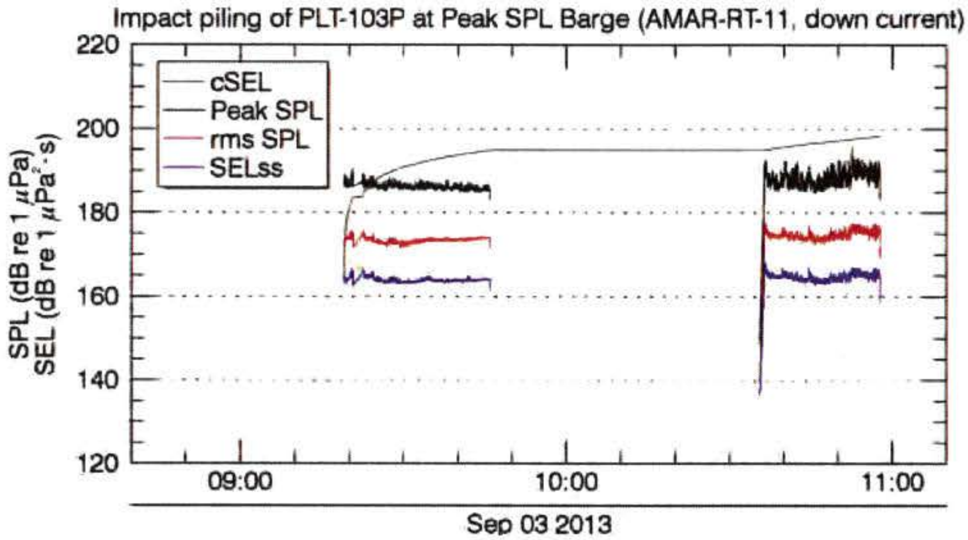



Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-103P measured 27 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

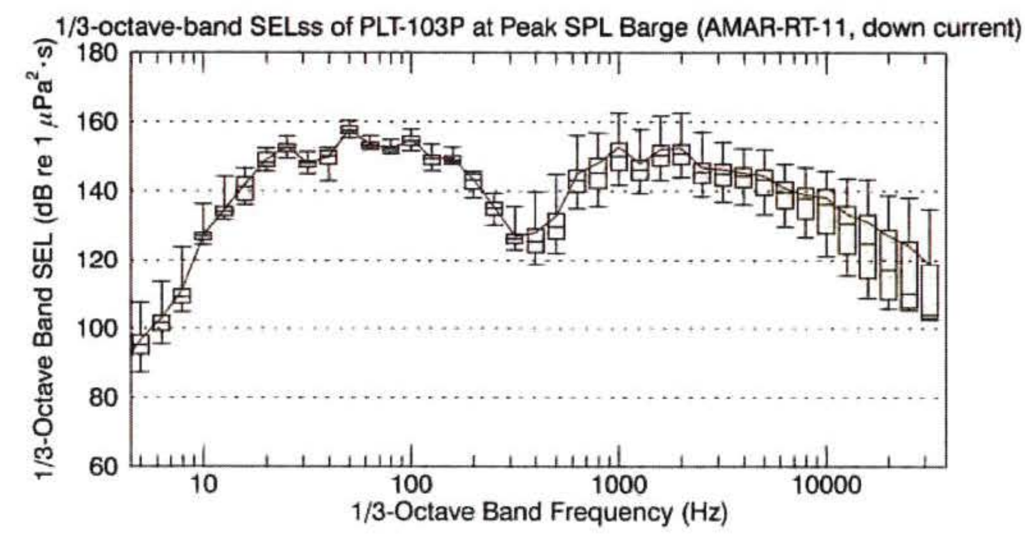



Figure 8. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-103P measured 27 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error bars indicate the maximum levels ($L_{max}$). 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-103P measured 27 ft from the pile at location Peak SPL Barge using AMAR-RT-11

| Sound level statistics* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 195.4 | 177.8 | 168.2 |
| $L_5$ | 190.8 | 176.3 | 165.9 |
| $L_{25}$ | 188.1 | 174.7 | 164.8 |
| $L_{50}$ | 186.7 | 173.8 | 164.1 |
| $L_{75}$ | 186.0 | 173.3 | 163.6 |
| $L_{95}$ | 185.4 | 172.5 | 163.2 |
| $L_{mean}$ | 187.6 | 174.2 | 164.4 |

* 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.2. Impact Pile-Driving Sound Levels cSEL East

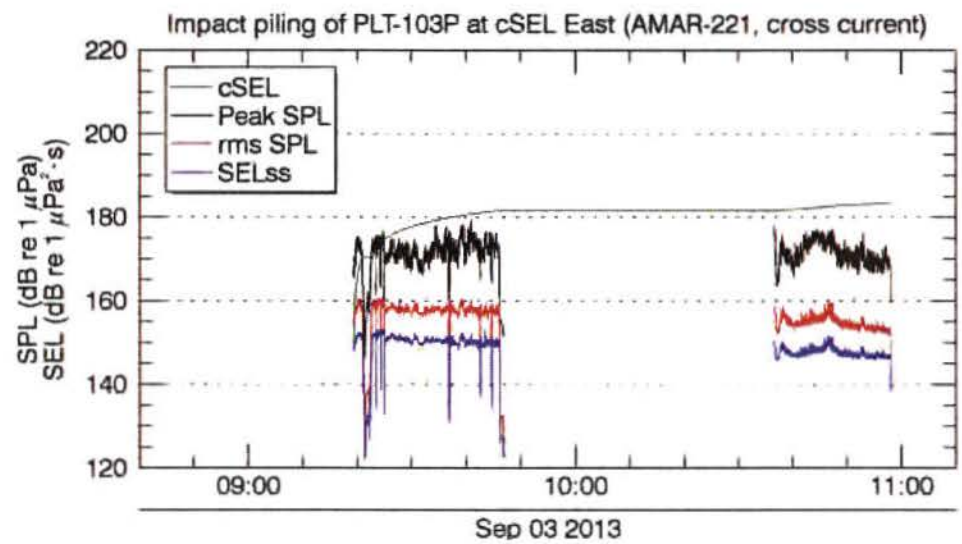



Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-103P measured 199 ft from the pile at location cSEL East using AMAR-221. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

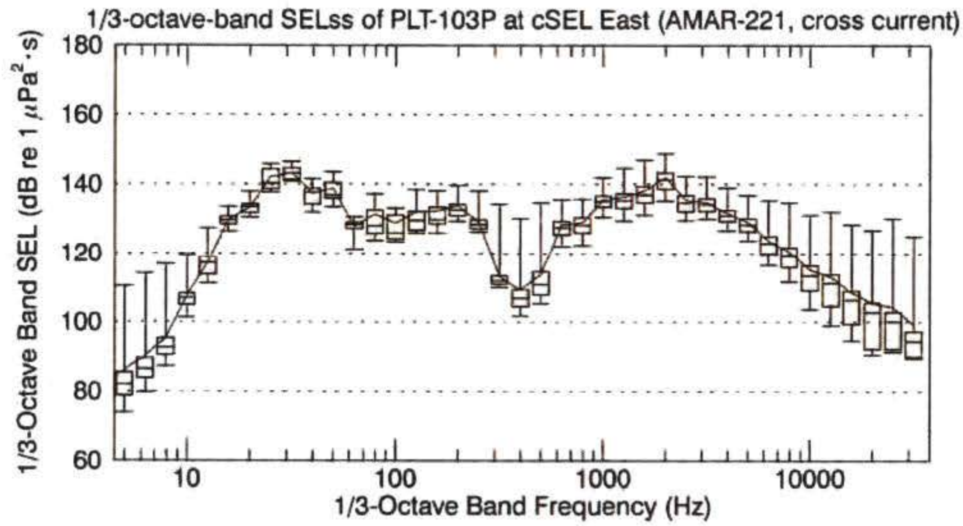



Figure 10.Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-103P measured 199 ft from the pile at location cSEL East using AMAR-221. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 12. Sound Levels for the pile driving of Test Pile PLT-103P measured 199 ft from the pile at location cSEL East using AMAR-221

| Sound level statistics* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 179.4 | 161.2 | 153.3 |
| $L_5$ | 175.8 | 159.3 | 151.8 |
| $L_{25}$ | 173.6 | 158.0 | 150.6 |
| $L_{50}$ | 171.8 | 156.8 | 149.4 |
| $L_{75}$ | 169.9 | 154.5 | 147.3 |
| $L_{95}$ | 167.6 | 152.9 | 146.4 |
| $L_{mean}$ | 172.5 | 156.8 | 149.4 |

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

## A.3. Impact Pile-Driving Sound Levels rms SPL East

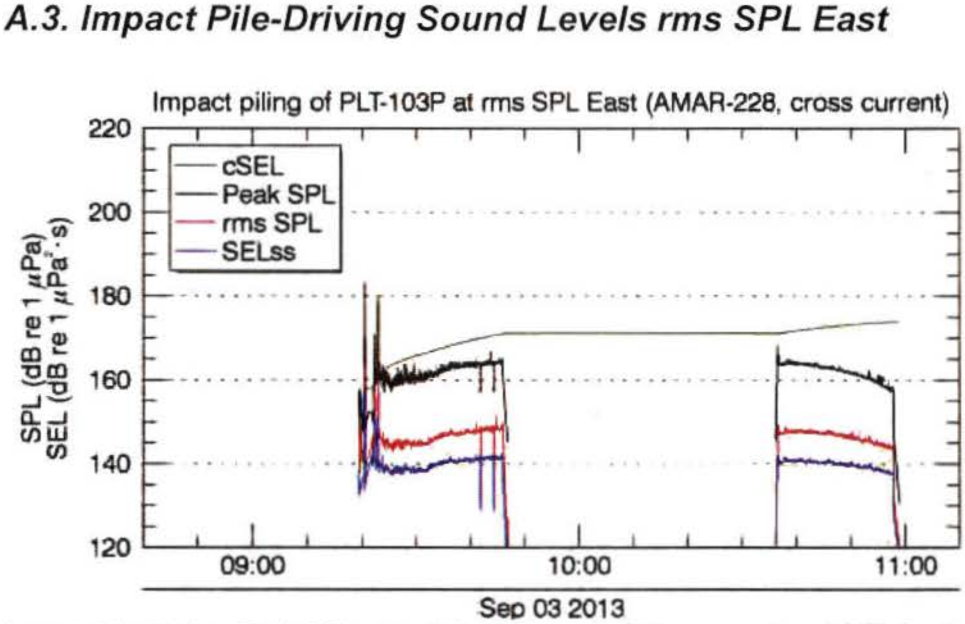



Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-103P measured 361 ft from the pile at location rms SPL East using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

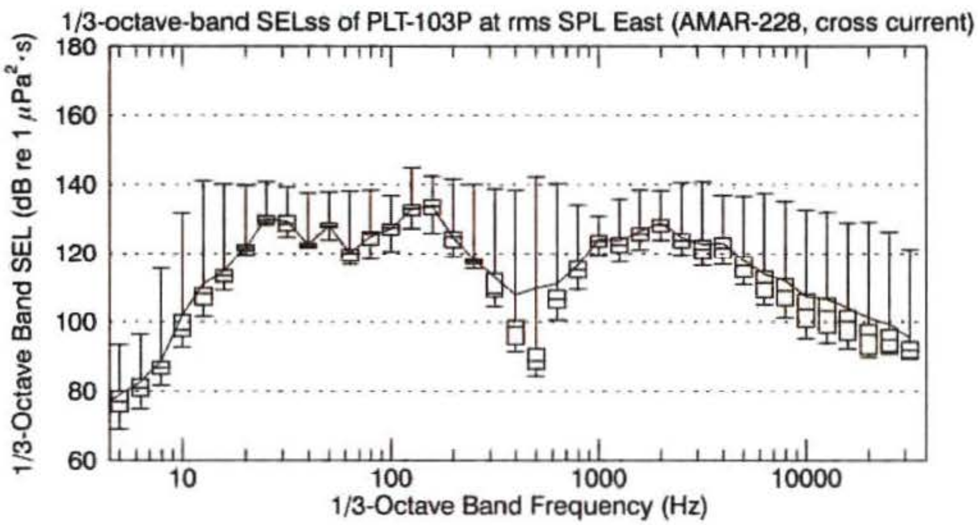



Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-103P measured 361 ft from the pile at location rms SPL East using AMAR-228. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 13. Sound Levels for the pile driving of Test Pile PLT-103P measured 361 ft from the pile at location rms SPL East using AMAR-228.

| Sound level statistics* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 168.4 | 151.5 | 142.5 |
| $L_5$ | 164.3 | 148.3 | 141.4 |
| $L_{25}$ | 163.7 | 147.6 | 140.7 |
| $L_{50}$ | 162.5 | 146.8 | 140.1 |
| $L_{75}$ | 160.7 | 145.2 | 138.9 |
| $L_{95}$ | 158.4 | 144.1 | 137.9 |
| $L_{mean}$ | 162.4 | 146.6 | 140.0 |

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

# Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile PLT-103 Installation

**Daily Memorandum for 04 September 2013**

*Submitted to:*

[redacted]

*Authors:*

[redacted]

JASCO Applied Sciences

[redacted]

03 January 2014

P001206-001

# 1. Summary

## 1.1. Pile Location and Monitoring Summary

PLT-103 is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 04 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 monitor sound levels during test pile installation (Figure 1, and Table 2). Pile driving occurred between during two periods between 15:05–16:26 EDT. Breaks often occurred during test pile installation. Breaks are approximate and varied between test piles. The breaks were generally due to transfer of pile equipment and marking test piles during installation. Pile driving occurred predominantly during the ebb current. Full ebb current occurred at 16:01 EDT.

Table 1. Summary of PLT-103 activities, 04 September 2013.

| | |
|---|---|
| Date: | 04 September 2013 |
| ***Pile-Driving Activity*** | |
| Test pile identifier: | PLT-103 |
| Pile diameter: | [redacted] |
| Water depth: | 8 ft |
| Hammer type: | Impact (IHC S-280) |
| Total hammer strikes: | 1875 |
| Total penetration: | 339 |
| Net duration of pile driving (hh:mm:ss): | ~00:35:00* |
| Maximum single strike energy: | 127 thousand foot-pounds (kip-ft), (172 kJ) |
| Total energy transferred: | 223,901 kip-ft (303 MJ) |
| ***Noise Attenuation System (NAS)*** | |
| Single-tier unconfined bubble curtain airflow rate: | 900–2150 cubic feet per minute (cfm), 34–80 psi |
| River conditions during pile driving: | Ebb tide, 0.3–0.8 knots (0.15–0.4 meters per second [m/s], depth dependent; Figure 5) |

* Pile installation duration is an approximation based on the number of strikes recorded in the GZA field log and an assumption of 57 strikes per minute, because the hammer read-out malfunctioned.

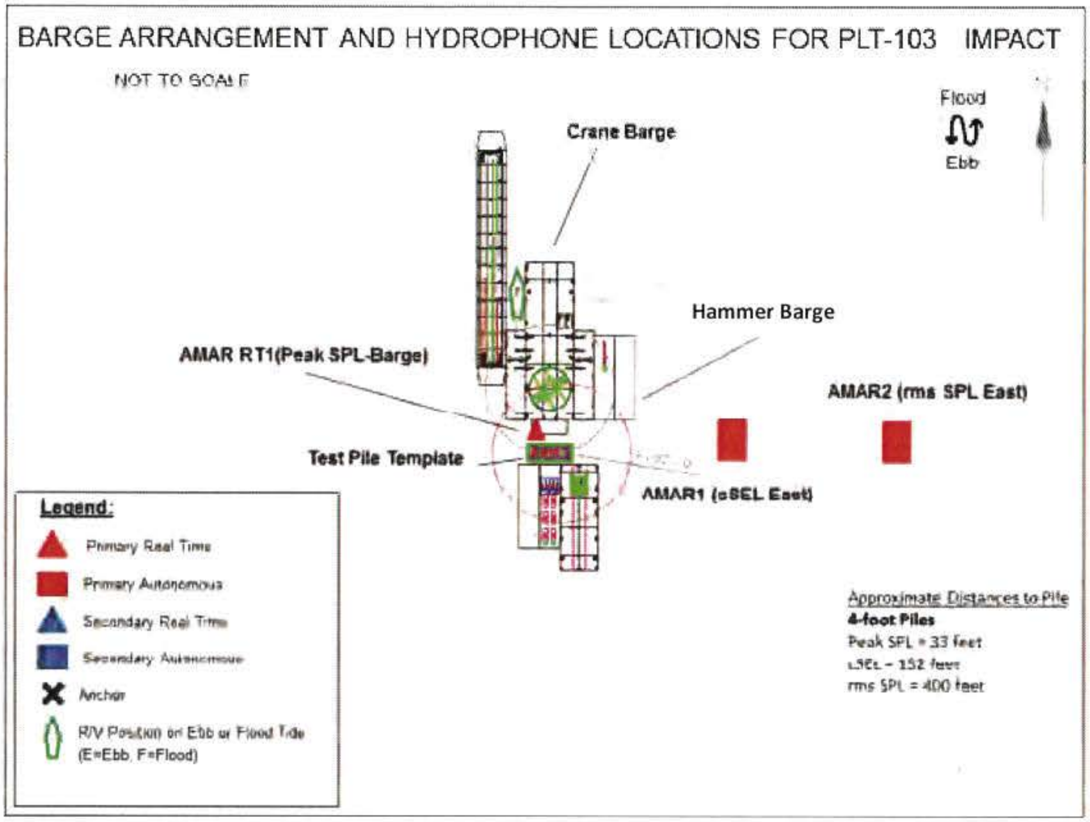



Figure 1. Plan view of pile and barge layout, 04 September 2013, PLT-103.

Table 2 provides the sound levels measured at each recorder. The maximum sound levels were measured at the Peak SPL Barge location, which was closest to the pile driving. Plots of the measured values, frequency distributions of 1/3 octave single-strike sound exposure level (SELss), and sound level statistics for the distribution of the measured data are presented in Appendix A.

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 re1 µPa) | cSEL (dB re 1 $\mu Pa^2 \cdot s$)* |
|---|---|---|---|---|---|
| Peak SPL Barge (up current) | AMAR-RT-11 | 30 | 8 | 193 | 194 |
| cSEL East (cross current) | AMAR-221 | 125 | 8 | 170 | 177 |
| rms SPL East (cross current) | AMAR-228 | 290 | 9 | 166 | 172 |

*Calculated by multiplying the average SELss by the number of strikes reported by the pile driving contractor..

## 1.2. NMFS Physiological and Behavioral Thresholds

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

The regression indicates that the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was less than 6 ft, and did not exceed NMFS criteria of a diameter of 40 ft for [redacted] piles. The diameter of the 187 dB re 1 µPa$^2$·s cumulative sound exposure level (cSEL) isopleth was estimated to be 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 The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

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

| Criteria | Estimated Mean Diameter (ft) |
|---|---|
| 206 dB re 1 µPa peak SPL | 6 |
| 187 dB re 1 µPa$^2$·s cSEL | 110* |
| 150 dB re 1 µPa rms SPL (1 s integration time) | 378 |

* At the end of pile driving

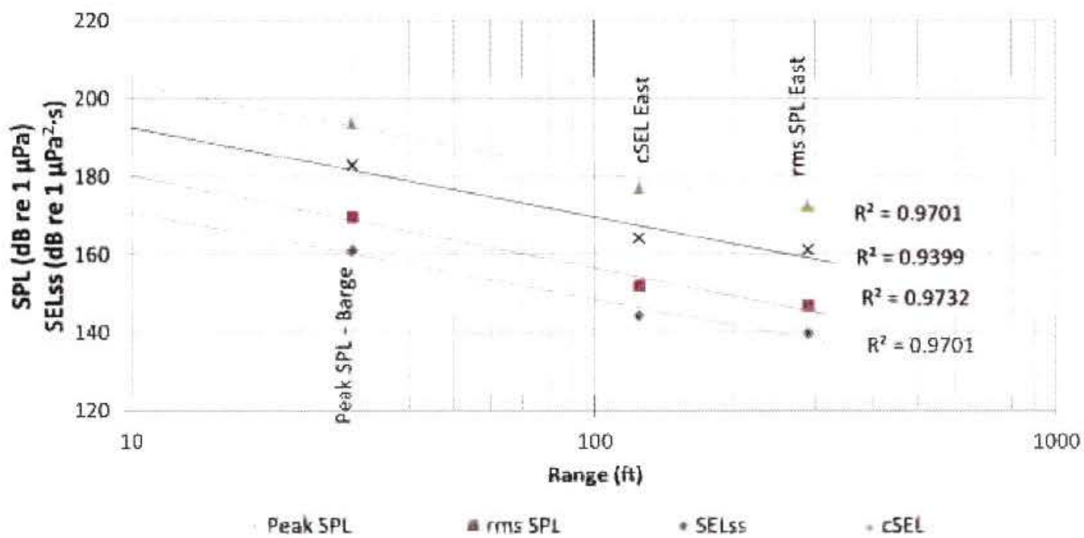



Figure 2. Regression based on mean values of the peak SPL, rms SPL, SELss, and cSEL from each recorder from pile driving of Test Pile PLT-103, 04 September 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents the total sound energy measured during the pile driving.

### 1.3. Observations

Pile driving occurred over two periods, 15:05-15:25 and 16:03-16:28. The hammer energy was nearly constant at 122±3 kip-ft during the first period, and 118±7 kip-ft during the second period (Figure 4). The current was an average of 0.5-0.6 knots during the entire period (Figure 5). Both autonomous recorders were cross-current (Figure 1). The NAS air pressure was 70–80 psi (1300–2150 cfm) during most of the pile driving, except a 2.5 min period from 16:03–16:05:30 when pressure fell to 34 psi due to a failure to open the valves from the compressors (Table 6). The measured sound levels at location Peak SPL Barge increased by 3–7 dB during the period when the NAS compressor valves were closed (Figure 3). Sound levels at locations cSEL East and rms SPL East did not show an increase during this period (Figure 3).

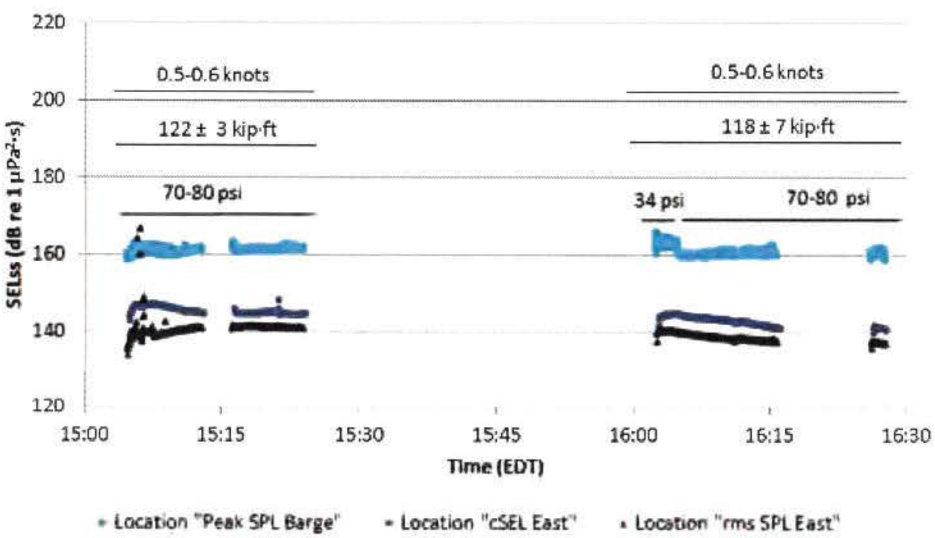



Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots). Air pressure to the rings was reduced from 16:03–16:05; however, sound levels only increased at location Peak SPL Barge.

Based on the regression, the estimated diameter of the 206 dB re 1 μPa peak SPL isopleth was 10 ft when the air pressure dropped to 34 psi, and did not exceed NMFS criteria of a diameter of 40 ft for [redacted] piles (Table 4). The diameter of the 187 dB re 1 μPa$^2$·s cSEL isopleth would have been 124 ft at the end of pile driving if 1875 strikes had occurred at these sound levels (Table 4).

Table 4. Estimated isopleth diameters for the NMFS physiological and behavioral thresholds using only the sound levels measured with no NAS, 16:03–16:05:30, 04 September 2013.

| Criteria | Estimated Mean Diameter (ft) |
|---|---|
| 206 dB re 1 μPa peak SPL | 10 |
| 150 dB re 1 μPa rms SPL (1 s integration time) | 398 |

# 2. Activity Logs

## 2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 04 September 2013.

Table 5. JASCO and construction activities for Test Pile PLT-103, 04 September 2013.

| Time (EDT) | Activity |
|---|---|
| 07:20 | Arrive at dock and leave for barges |
| 07:29 | Start deploying AMAR recorders |
| 07:53 | Complete deploying AMAR recorders |
| 08:00 | Transfer to barge and deploy Real Time AMAR system |
| 08:20 | Complete Real Time AMAR system deployment, begin monitoring pile driving activity |
| 15:05 | Pile driving begins |
| 16:28 | Pile driving completed, start to retrieve all recorders |
| 17:10 | All AMAR retrieved. Head to dock |
| 17:20 | Begin data download at dock, securing equipment. |
| 18:20 | All work complete. |

## 2.2. Pile Driving Logs

### 2.2.1. NAS

Noise Attenuation System (NAS) Used: Single-tier unconfined bubble curtain.

NAS Settings: 900 – 2150 cfm, 34 – 80 psi

Table 6. NAS settings during pile driving at PLT-103, 04 September, 2013.

| Time (EDT) | Volume/min (cfm) | Pressure (psi) |
|---|---|---|
| 15:05–15:21 | 1300–1500 | 70–75 |
| 16:03–16:05 | 900–1000 | 34* |
| 16:06–1616 | 1300–2150 | 70–80f |
| 16:26–16:28 | 1250–1350 | 70–75 |

*After two minutes of pile driving it was discovered that the valve from the compressors to the air tanks was not open. 34 psi was the pressure in the air tanks when the valve was opened at 16:05.

### 2.2.2. Impact Hammering Log

Total energy: 223,901 kip-ft (303 MJ)

Total number of strikes: 1875

Maximum per-strike energy: 127 kip-ft (172 kJ)

Net pile driving duration (hh:mm:ss): ~00:35:00*

* Pile installation duration is an approximation based on the number of strikes recorded in the GZA field log and an assumption of 57 strikes per minute, because the hammer read-out malfunctioned.

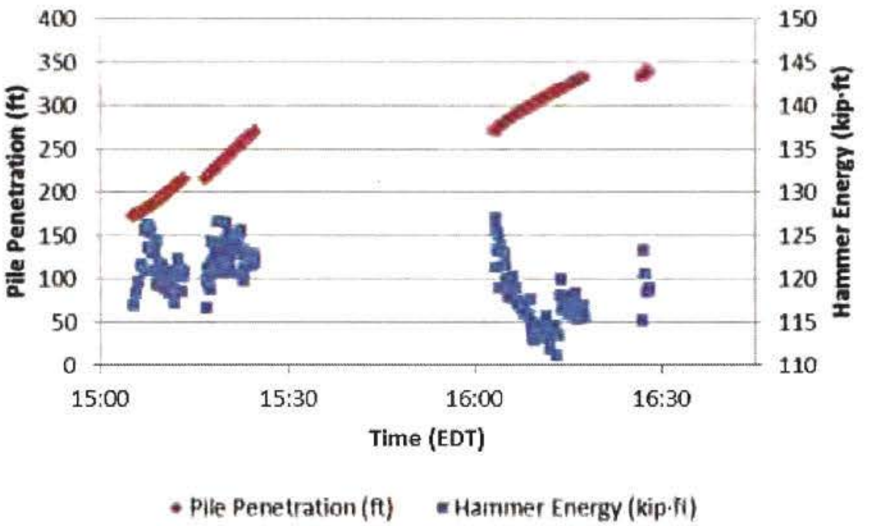



Figure 4. Hammer energy (kip-ft) and pile penetration (ft) during pile driving of PLT-103, 04 September 2013.

## 3. Weather and River Conditions

Table 7 provides the predicted currents at the project site on 04 September, 2013. Figure 5 provides the Acoustic Doppler Current Profiler (ADCP)-measured currents. Figure 6 provides the speed of sound in water, based on salinity and temperature measured using the CTD.

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

| | |
|---|---|
| Weather conditions: | Sunny, 3–5 knots Westerly wind. |
| Full ebb current: | 16:01 (-1.9 knots) |
| Slack current: | 12:24, 18:34 |
| Full flood current: | 09:49 (1.1 knots) |

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

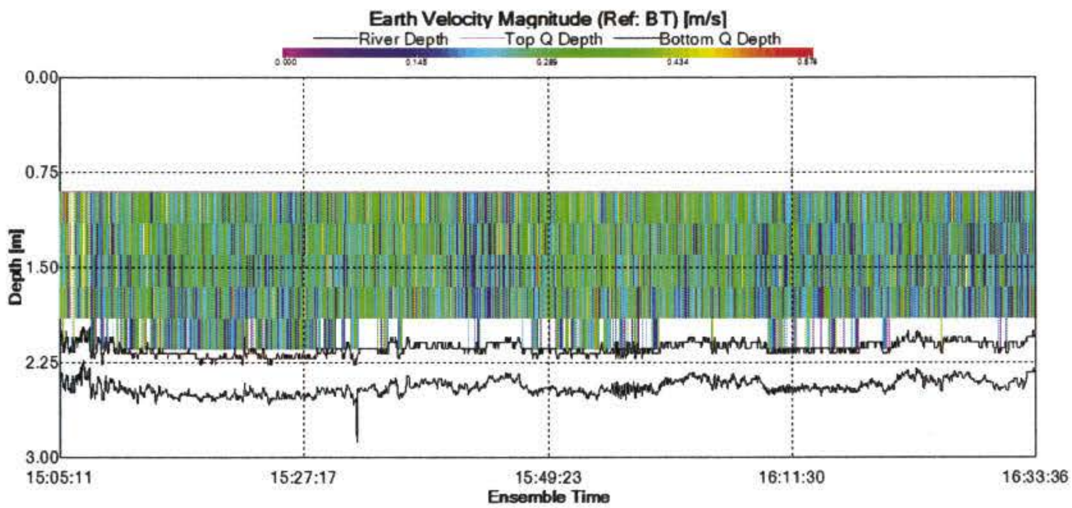



Figure 5. ADCP data from 04 September 2013 at location Peak SPL Vessel location, times are in EDT

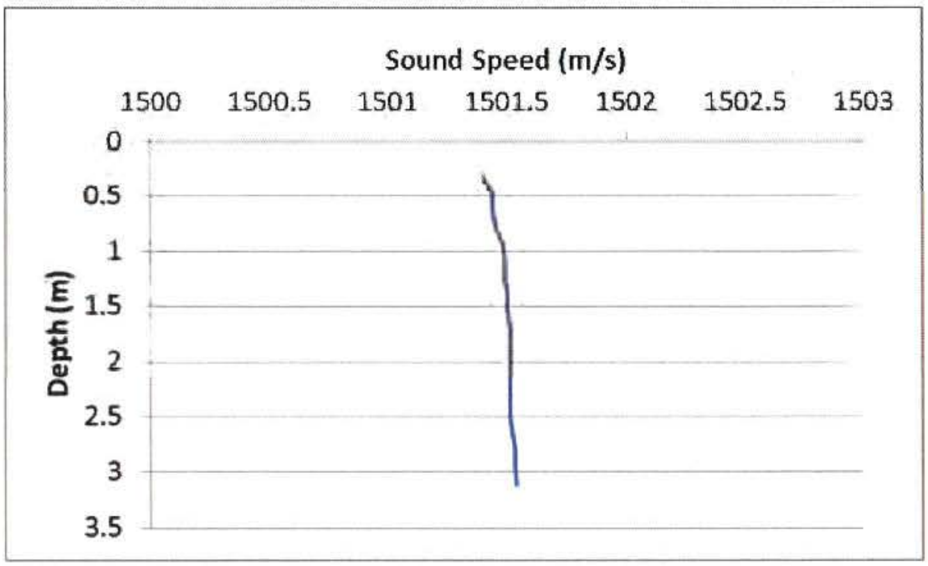



Figure 6. CTD cast performed at 09:09 EDT from location Peak SPL Vessel.

# 4. Monitoring Equipment

## 4.1. Real-time Monitoring Equipment

Table 8 provides information on the real-time monitoring equipment used on 04 September 2013. Table 9 provides location information on the real-time recorders

Table 8. Real-time monitoring equipment for Test Pile PLT-103, 04 September 2013.

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

Table 9. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 04 September 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time | Water Depth (ft) | Distance to Pile (ft) |
|---|---|---|---|---|---|---|
| Peak SPL, Barge | AMAR-RT-11 | 41.071810 | 73.9151 | 08:20 | 8 | 30 |

## 4.2. Autonomous Monitoring Equipment

Table 10 provides information on the autonomous monitoring equipment used on 04 September 2013. Table 11 provides the locations of the autonomous recorders.

Table 10. Autonomous acoustic monitoring equipment deployed 4 September 2013.

| Acoustic Data Logger | | Units deployed |
|---|---|---|
| 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: | -199.8 dB re 1 V/µPa | 1 |

Table 11. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 04 September 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time | Water Depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| cSEL East (cross current) | AMAR-221 | 41.07154 | 73.91470 | 7:39 | 8 | 125 |
| rms SPL East (cross current) | AMAR-228 | 41.07134 | 73.91416 | 7:53 | 9 | 290 |

# Appendix A. Pile Driving Plots

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

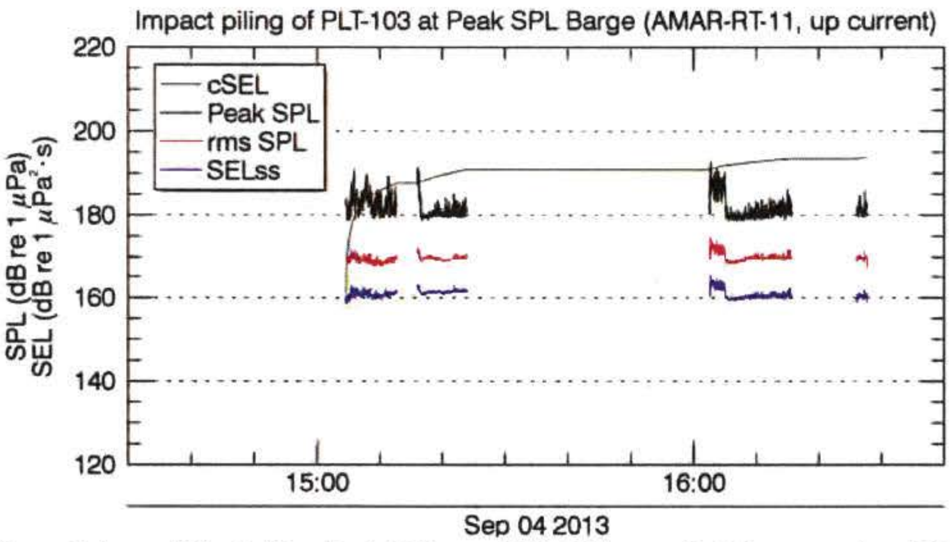



Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-103 measured 30 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

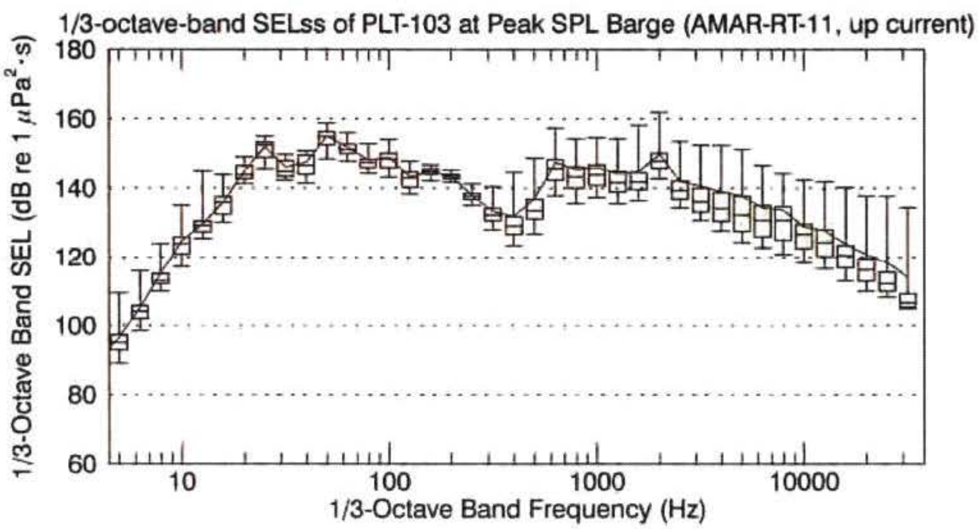



Figure 8.Distribution 1/3-octave-band SELss for the pile driving of Test Pile PLT-103 measured 30 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). 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-103 measured 30 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 192.9 | 175.0 | 165.6 |
| $L_5$ | 187.9 | 171.8 | 162.8 |
| $L_{25}$ | 182.9 | 170.0 | 161.4 |
| $L_{50}$ | 180.9 | 169.5 | 160.8 |
| $L_{75}$ | 180 | 169.0 | 160.1 |
| $L_{95}$ | 179.2 | 168.3 | 159.6 |
| $L_{mean}$ | 182.9 | 169.7 | 161.0 |

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

## A.2. Impact Pile-Driving Sound Levels at cSEL East

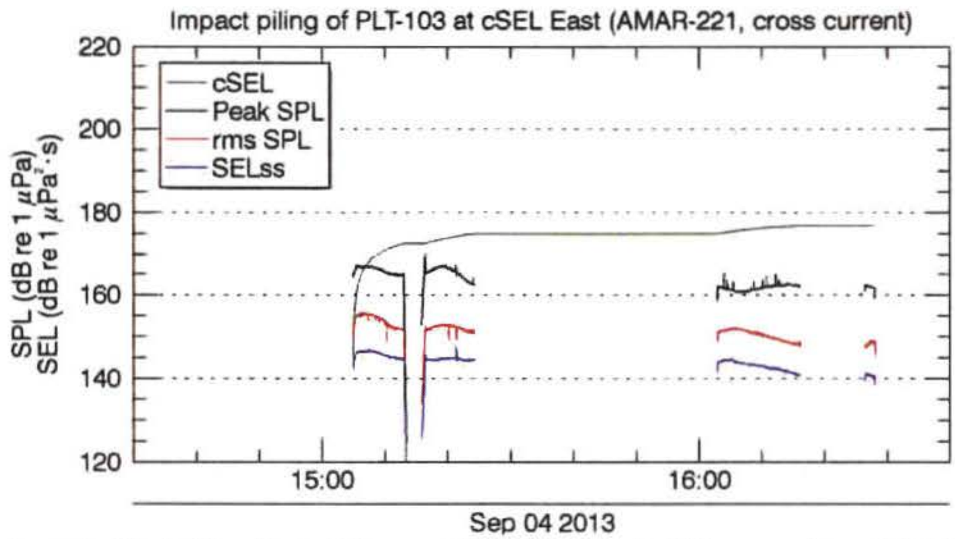



Figure 9. *Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-103 measured 125 ft from the pile at location cSEL East using AMAR-221. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

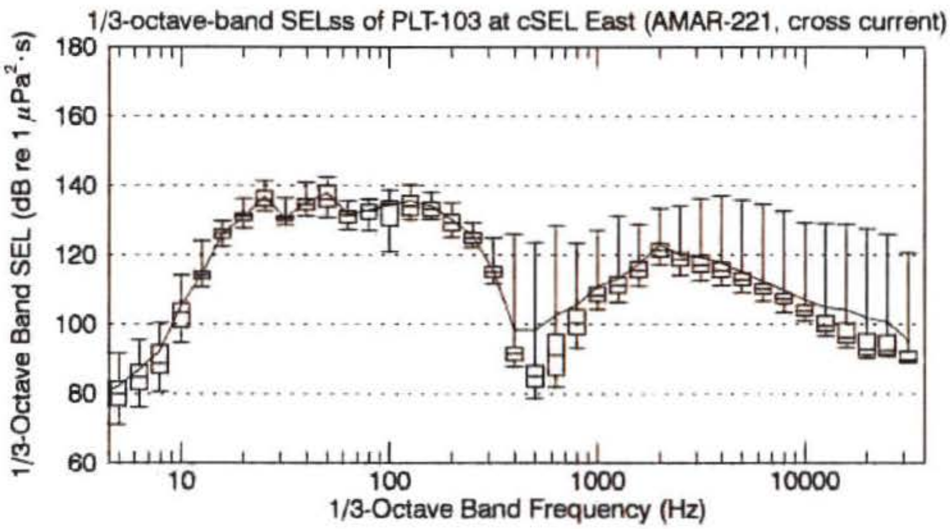



Figure 10. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-103 measured 125 ft from the pile at location cSEL East using AMAR-221. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 13. Sound levels for the pile driving of Test Pile PLT-103 measured 125 ft from the pile at location cSEL East using AMAR-221.

| Sound level statistic* | peak SPL (dB re 1 μPa) | rms SPL (dB re 1 μPa) | SELss (dB re 1 μPa²·s) |
|---|---|---|---|
| $L_{max}$ | 170.2 | 155.8 | 147.9 |
| $L_5$ | 166.8 | 155.2 | 146.5 |
| $L_{25}$ | 165.8 | 152.5 | 144.8 |
| $L_{50}$ | 162.7 | 151.7 | 144.3 |
| $L_{75}$ | 161.8 | 150.4 | 142.9 |
| $L_{95}$ | 160.8 | 148.4 | 140.9 |
| $L_{mean}$ | 164.2 | 152.0 | 144.2 |

* 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 at rms SPL East

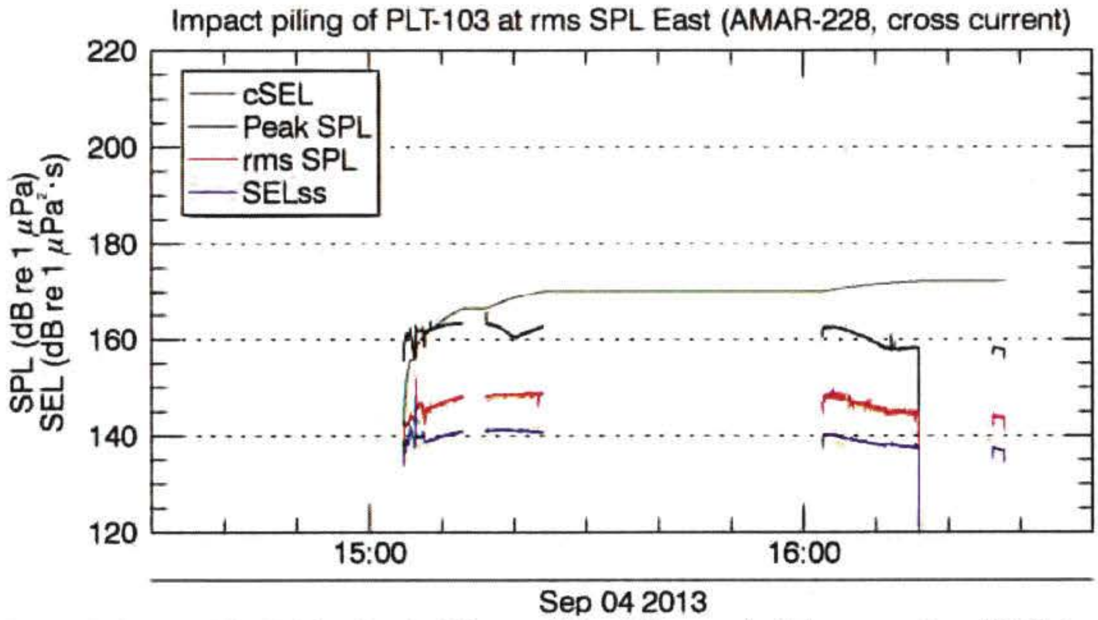



Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-103 measured 290 ft from the pile at location rms SPL East using AMAR-228.). For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

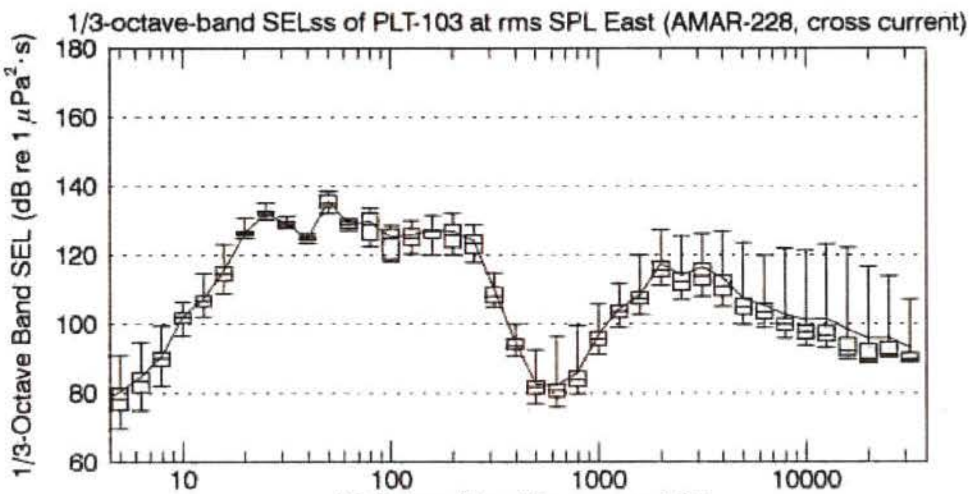



Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-103 measured 290 ft from the pile at location rms SPL East using AMAR-228. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 14. Sound levels for the pile driving of Test Pile PLT-103 measured 290 ft from the pile at location rms SPL East using AMAR-228

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 165.5 | 151.7 | 148 |
| $L_5$ | 163.2 | 148.7 | 141.2 |
| $L_{25}$ | 162.4 | 148.3 | 140.8 |
| $L_{50}$ | 161.5 | 146.9 | 139.6 |
| $L_{75}$ | 159.1 | 145.3 | 138.2 |
| $L_{95}$ | 157.9 | 143.7 | 137.2 |
| $L_{mean}$ | 161.2 | 147 | 139.7 |

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

# Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 104P Installation

**Daily Memorandum for 12 September 2013**

*Submitted to:*

[redacted]


*Authors:*

[redacted]

JASCO Applied Sciences

[redacted]


03 January 2014

P001206-001

# 1. Summary

## 1.1. Pile Location and Monitoring Summary

Test Pile PLT-104P is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 12 September 2013 (Table 1). One real-time acoustic monitoring system and three autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors, LLC (TZC) to measure sound levels (Figure 1, Table 2). Recorder cSEL 250 ft West (AMAR-221) was observed to be struck by a tug and was not recovered after repeated attempts to locate it. Pile driving occurred between 11:08–11:39 Eastern Daylight Time (EDT), and full ebb tide occurred at 09:03 EDT, slowing to slack tide at 12:34 EDT.

Pile driving was temporarily interrupted at approximately 11:11 when it was discovered that the compressor outlet valves for the NAS were closed. Pile driving resumed at 11:12 when the NAS was operating normally.

Table 1. Summary of Test Pile PLT-104P activities, 12 September 2013.

| | |
|---|---|
| Date: | 12 September 2013 |
| ***Pile-Driving Activity*** | |
| Test pile identifier: | PLT-104P |
| Pile diameter: | [redacted] |
| Water depth: | 9 ft |
| Hammer type: | Impact (IHC S-280) |
| Total hammer strikes: | 1938 |
| Total penetration : | 336 ft |
| Net duration of pile driving (hh:mm:ss): | 00:27:00 |
| Maximum single strike energy: | 129 thousand foot-pounds (kip-ft), (175 kilojoules [kJ]) |
| Total energy transferred: | 230,248 kip-ft (312 MJ) |
| ***Noise Attenuation System (NAS)*** | |
| Single-tier unconfined bubble curtain airflow rate: | 1400–1600 cubic feet per minute (cfm), 55–135 pounds per square inch (psi) |
| River conditions during pile driving: | Ebb to Slack tide, 0–0.6 knots (0–0.3 meters per second [m/s] depth dependent (see Table 7, and Figure 4) |

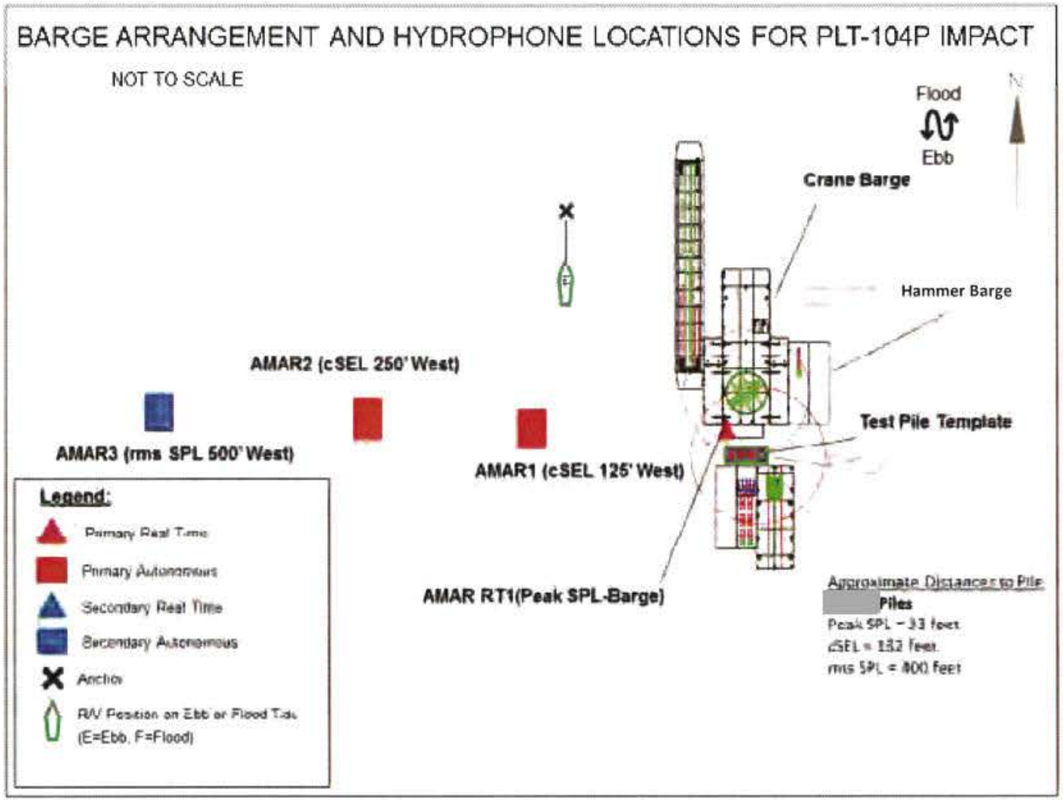



Figure 1. Plan view of pile and barge layout, 12 September 2013, Test Pile PLT-104P.

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

| Location | AMAR ID | Distance to pile (ft) | Water depth (ft) | Max peak SPL (dB re 1 µPa) | cSEL (dB re 1 µPa$^2$s)* |
|---|---|---|---|---|---|
| Peak SPL Barge (up current) | AMAR-RT-11 | 32 | 10 | 204 | 201 |
| cSEL West (cross current) | AMAR-228 | 201 | 9 | 180 | 175 |
| cSEL West ** (cross current) | AMAR-221 | 280 | 9 | n/a | n/a |
| rms SPL West (cross current) | AMAR-175 | 507 | 9 | 165 | 165 |

*Calculated by multiplying the average SELss by the number of strikes reported by the pile driving contractor .
** cSEL 250-ft West (AMAR-221) was not recovered.

## 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 SELs 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 26 ft, and did not exceed NMFS criteria of a diameter of 40 ft for [redacted] piles. The diameter of the 187 dB re 1 μPa$^2$·s cumulative sound exposure level (cSEL) isopleth was estimated to be 181 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 181 ft for most of the pile driving operation. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

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

| Criteria | Estimated mean diameter (ft) |
|---|---|
| 206 dB re 1 μPa peak SPL | 26 |
| 187 dB re 1 μPa$^2$·s cSEL | 181* |
| 150 dB re 1 μPa rms SPL (1 s integration time) | 424 |

*At the end of pile driving

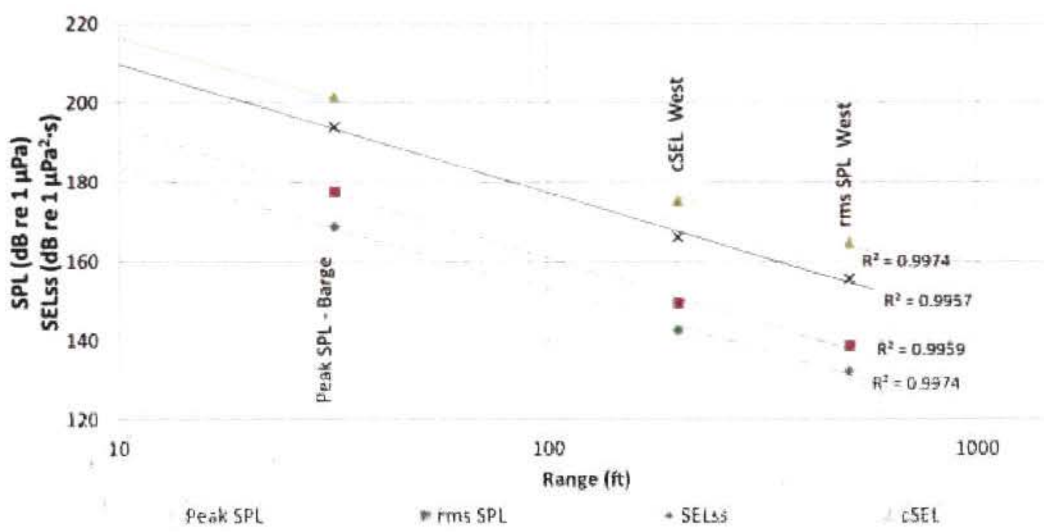



Figure 2. Regression based on mean values of the peak SPL, rms SPL, SELss, and cSEL from each recorder from pile driving of Test Pile PLT-104P, 12 September 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents the total sound energy measured during the pile driving.

## *1.3. Observations*

Test Pile PLT-104P was driven during the end of ebb tide, and pile driving continued during slack tide (Figure 3). Hammer energy ranged from 111 to 125 kip-ft, with initial strikes of 104 kip-ft and 129 kip-ft. Air pressure at the NAS dropped from 135 to 0 psi (1500–0 cfm) during the first four minutes of pile driving (11:08-11:11, Figure 3) because the valve from the air-compressor to the air-tank was closed. Pile driving stopped and resumed with proper NAS operation at 11:12. Air pressure ranged between 55 and 70 psi (1400-1600 cfm) for the remainder of the pile driving. Once the compressor valve was opened sound levels at all three recorders decreased approximately 10 dB at every position (based on comparison of SEL,Figure 3). The sound level variation at location rms SPL West was qualitatively different than the other recorders (Figure 3); however, the sound levels were well below NMFS and NYSDEC physiological and behavioral thresholds.

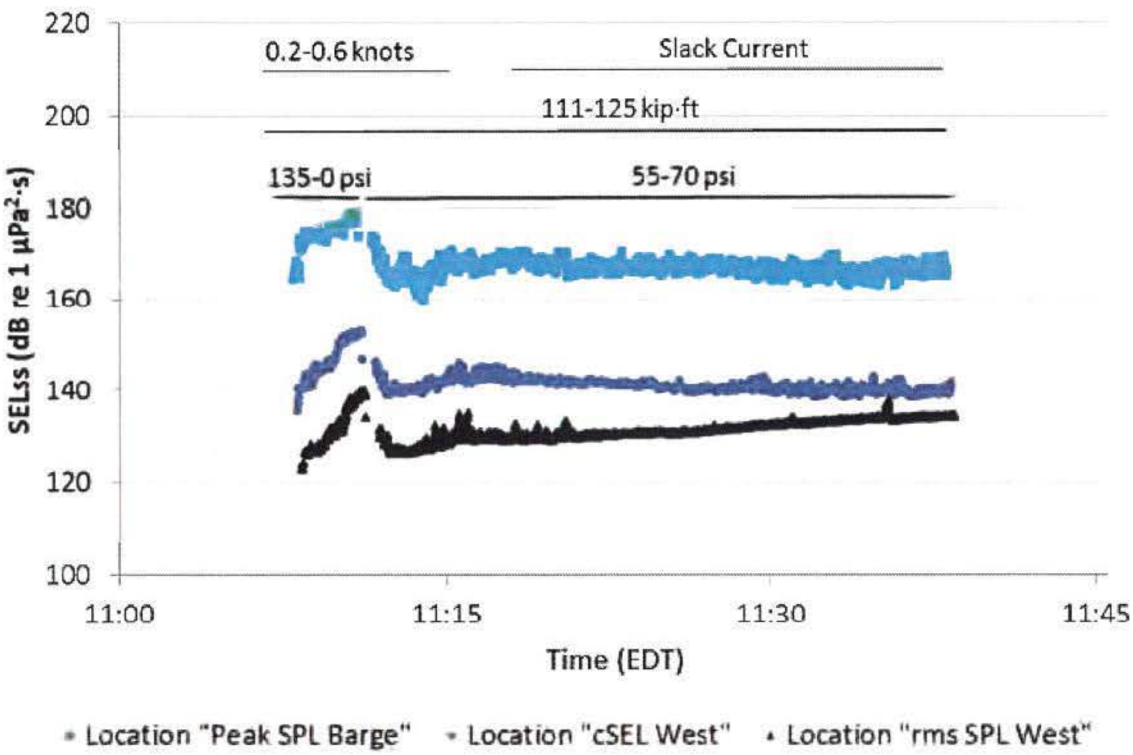



Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots). The valves from the NAS air-compressors to the air tanks were off from 11:08-11:11, which caused the air pressure to drop from 135 to 0 psi. Sound levels rose over this time period and dropped by approximately 10 dB 11:12 when the NAS operation returned to normal.

Based on the regression of the sound levels for the period when air pressure dropped to 0 cfm, the estimated diameter of the 206 dB re 1 µPa peak SPL isopleth was 8 ft, and exceeded NMFS criteria of a diameter of 40 ft for [redacted] for approximately 30 seconds (Table 4).. The diameter of the 187 dB re 1 µPa$^2$·s cSEL isopleth would have been 330 ft at the end of pile driving if 1938 strikes had occurred at these sound levels.

Table 4. Estimated isopleth diameters for the NMFS and NYSDEC physiological and behavioral thresholds using only the sound levels measured with NAS off, 11:10:30-11:11:00, 12 September 2013.

| Criteria | Estimated Mean Diameter (ft) |
|---|---|
| 206 dB re 1 µPa peak SPL | 48 |
| 150 dB re 1 µPa rms SPL (one second integration time) | 774 |

# 2. Activity Logs

## 2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 12 September 2013.

Table 5. JASCO and construction activities for 12 September 2013.

| Time (EDT) | Activity |
|---|---|
| 04:50 | Arrive at dock, prep recorders, wait for sunlight |
| 06:11 | Leave dock for job site |
| 06:45 | Deploy AMARs; stand by |
| 07:11 | Transfer to barge, deploy AMAR-RT |
| 07:36 | Picking hammer |
| 11:00 | AMAR 221 at 280 ft dragged |
| 11:07 | NAS on |
| 11:08 | Pile driving starts |
| 11:39 | Pile driving stops |
| 12:00 | Retrieve and download data |
| 14:08 | All work complete. |

## 2.2. Pile Driving Logs

### 2.2.1. NAS

NAS used: Single-tier unconfined bubble curtain

NAS Settings: 1400–1600 cfm, 55–135 psi

Table 6. NAS setting recorded during pile driving at Test Pile PLT-104P, 12 September 2013.

| Time (EDT) | Volume/min (cfm) | Pressure (psi) |
|---|---|---|
| 11:07 | 1500 | 135 |
| 11:12 | 0 | 0 |
| 11:13 | 1483 | 70 |
| 11:38 | 1400–1600 | 55–70 |

### *2.2.2. Impact Hammering Log*

Total energy: 230,248 kip-ft (312 MJ)

Total number of strikes: 1938

Maximum per-strike energy: 129 kip-ft (175 kJ)

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

## 3. Weather and River Conditions

Table 7 provides the predicted currents at the project site on 12 September, 2013. Figure 4 provides the Acoustic Doppler Current Profiler (ADCP)-measured currents. Figure 5 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: | 09:03, 22:32 (1.5 knots) |
| Slack current: | 00:43, 05:43, 12:34, 18:34 |
| Full flood current: | 03:09, 15:18 (1.3 knots) |

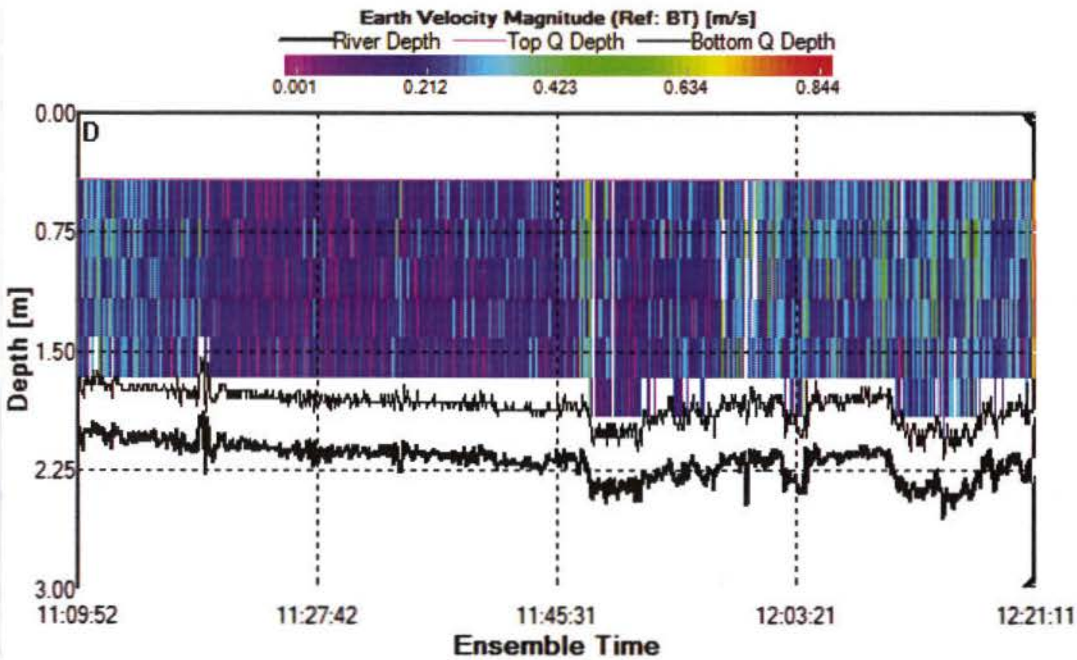



Figure 4. ADCP data from 12 September 2013 from the Alpine vessel, located 625 ft NW of the pile (41.07417 N, 73.91453 W), times are in EDT.

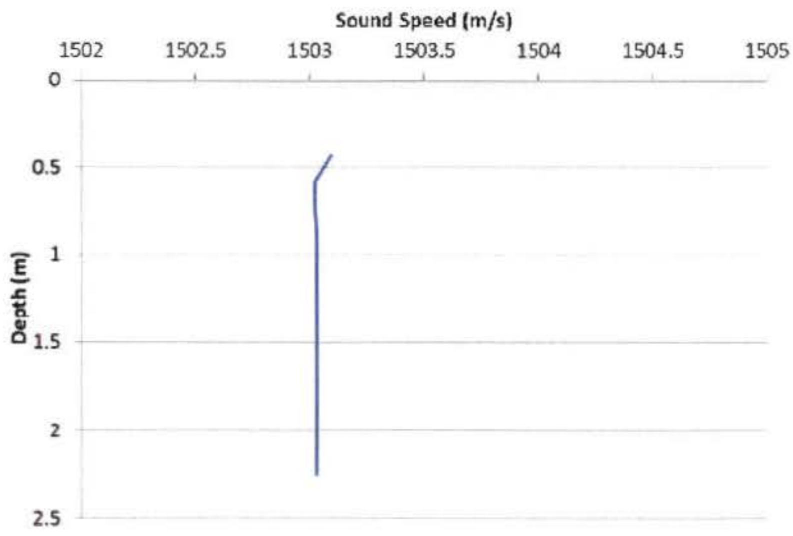



Figure 5. CTD cast performed at 07:59 EDT from the Alpine vessel, located 625 ft NW of the pile (41.07417 N, 73.91453 W).

# 4. Monitoring Equipment

## 4.1. Real-time Monitoring Equipment

Table 8 provides information on the real-time monitoring equipment used on 12 September 2013. Table 9 provides location information on the real-time recorders.

Table 8. Real-time monitoring equipment for Test Pile PTL-104P, 12 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, 12 September 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time (EDT) | Water depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| Peak SPL Barge | AMAR-RT11 | 41.07132 | 73.9127 | 07:11 | 10 | 32 |

## 4.2. Autonomous Monitoring Equipment

Table 10 provides information about the autonomous monitoring equipment used on 12 September 2013. Table 11 provides the locations of the autonomous recorders.

Table 10. Autonomous recording equipment for Test Pile PTL-104P, 12 September 2013.

| Equipment used | | Units deployed |
|---|---|---|
| ***Acoustic data logger*** | | |
| Model: | AMAR G3 (JASCO Applied Sciences) | 3 |
| *SpectroPlotter* version: | 6.0.1 | 3 |
| ***Hydrophone*** | | |
| Model: | M8E-51-0dB (GTI) | 3 |
| AMAR 221 Sensitivity: | -199.9 dB re 1 V/μPa | 1 |
| AMAR 228 Sensitivity: | -200.1 dB re 1 V/μPa | 1 |
| AMAR 175 Sensitivity: | -200.1 dB re 1 V/μPa | 1 |

Table 11. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 12 September 2013

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time (EDT) | Water depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| cSEL West (cross current) | AMAR-228 | 41.07168 | -73.9133 | 06:34 | 9 | 201 |
| cSEL West (cross current)* | AMAR-221 | 41.07155 | -73.9138 | 06:39 | 9 | 280 |
| rms SPL West (cross current) | AMAR-175 | 41.07174 | -73.9146 | 06:44 | 9 | 507 |

* not retrieved.

# Appendix A. Pile Driving Plots

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

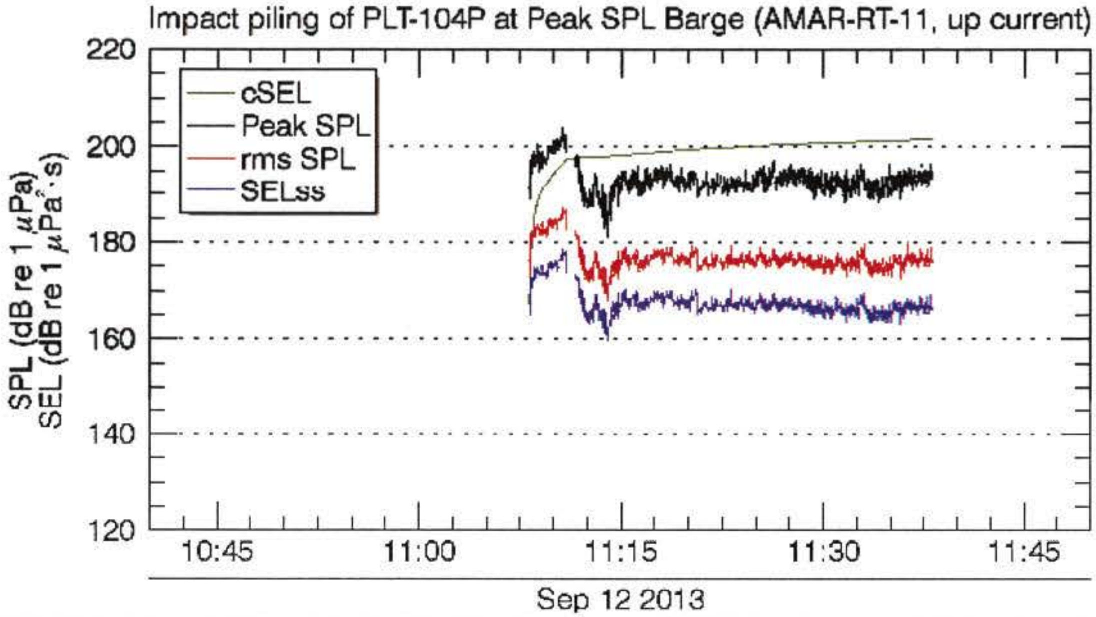
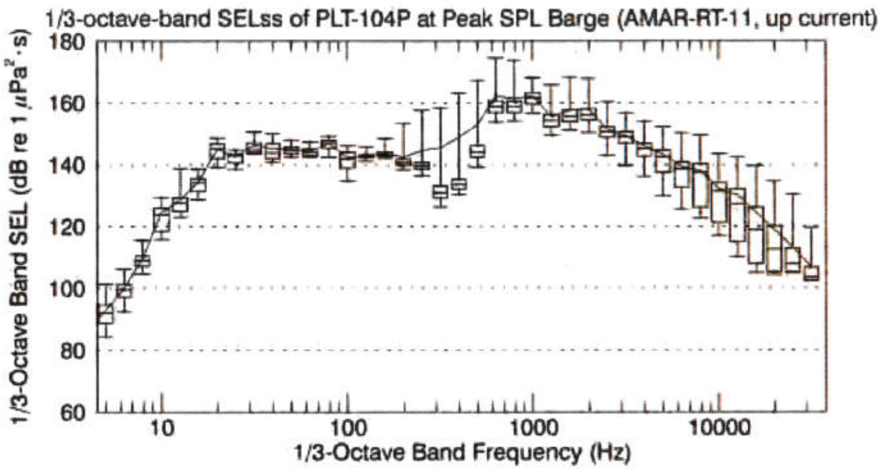
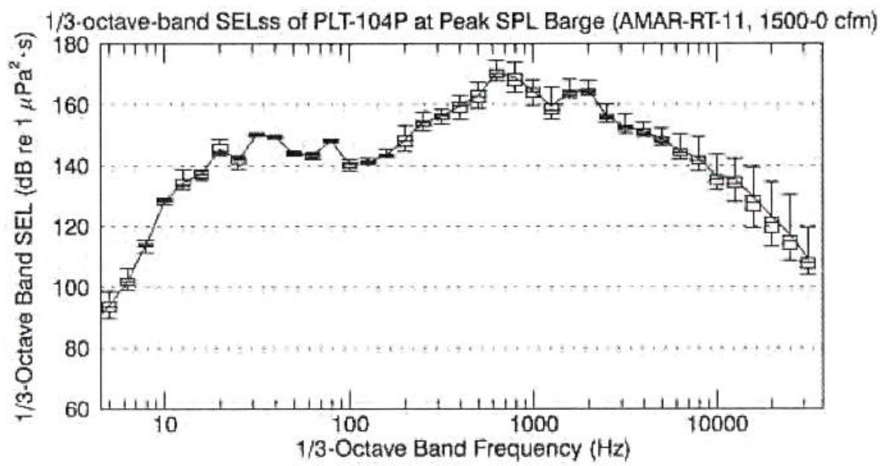



Figure 6. *Impact Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-104P measured 32 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time. The valves from the NAS air-compressors to the air tanks were off from 11:08-11:11, which caused the air volume delivered to the bubble rings to drop from 135 to 0 psi (1500 to 0 cfm). Sound levels rose over this time period and returned to their expected levels at 11:12 when the NAS operation returned to normal.


1/3-octave-band SELss of PLT-104P at Peak SPL Barge (AMAR-RT-11, up current)
1/3-Octave Band SEL (dB re 1 µPa²·s)
180
160
140
120
100
80
60
10
100
1000
10000
1/3-Octave Band Frequency (Hz)


1/3-octave-band SELss of PLT-104P at Peak SPL Barge (AMAR-RT-11, 1500-0 cfm)
1/3-Octave Band SEL (dB re 1 µPa²·s)
180
160
140
120
100
80
60
10
100
1000
10000
1/3-Octave Band Frequency (Hz)

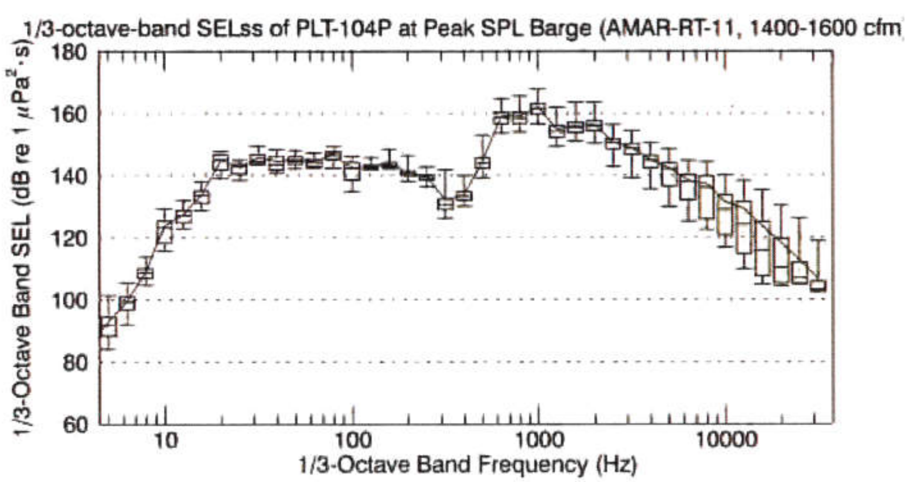

1/3-octave-band SELss of PLT-104P at Peak SPL Barge (AMAR-RT-11, 1400-1600 cfm
1/3-Octave Band SEL (dB re 1 µPa²·s)
180
160
140
120
100
80
60
10
100
1000
10000
1/3-Octave Band Frequency (Hz)

Figure 7. Distribution of 1/3-octave SELss for the pile driving of Test Pile PLT-104P measured 32 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$). Top: All NAS settings (1863 strikes). Middle: 135-0 psi (1500–0 cfm, 151 strikes). Bottom: NAS at 55-70 psi (1400–1600 cfm, 1712 strikes).

Table 12. Sound levels for the pile driving of Test Pile PLT-104P measured 32 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 204.0** | 187.2 | 178.6 |
| $L_5$ | 198.5 | 183.1 | 174.3 |
| $L_{25}$ | 194.0 | 177.1 | 167.9 |
| $L_{50}$ | 192.7 | 176.1 | 166.9 |
| $L_{75}$ | 191.4 | 175.2 | 166.0 |
| $L_{95}$ | 189.1 | 173.6 | 164.4 |
| $L_{mean}$ | 193.9 | 177.6 | 168.6 |

*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 ($L_{50}$).

** The valves from the NAS air-compressors to the air tanks were off from 11:08-11:11, which caused the air volume delivered to the bubble rings to drop from 135 to 0 psi (1500 to 0 cfm). Sound levels rose over this time period and returned to their expected levels at 11:12 when the NAS operation returned to normal.

## A.2. Impact Pile-Driving Sound Levels cSEL West

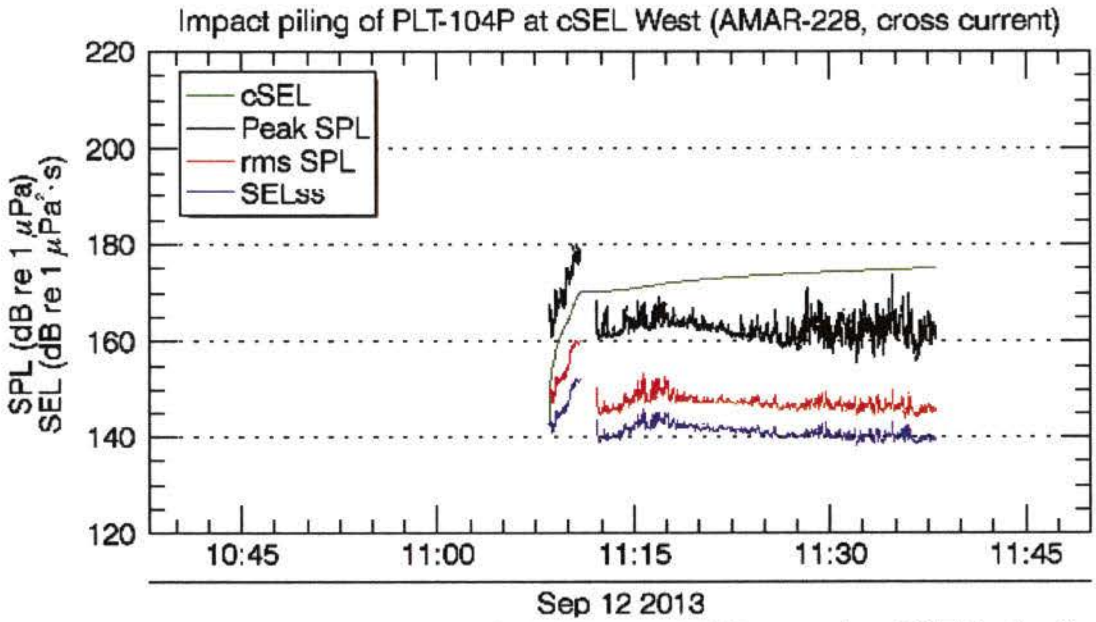



Figure 8. *Impact Pile Driving*: Peak and rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-104P measured 201 ft from the pile at location cSEL West using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time. The valves from the NAS air-compressors to the air tanks were off from 11:08-11:11, which caused the air volume delivered to the bubble rings to drop from 135 to 0 psi (1500 to 0 cfm). Sound levels rose over this time period and returned to their expected levels at 11:12 when the NAS operation returned to normal.

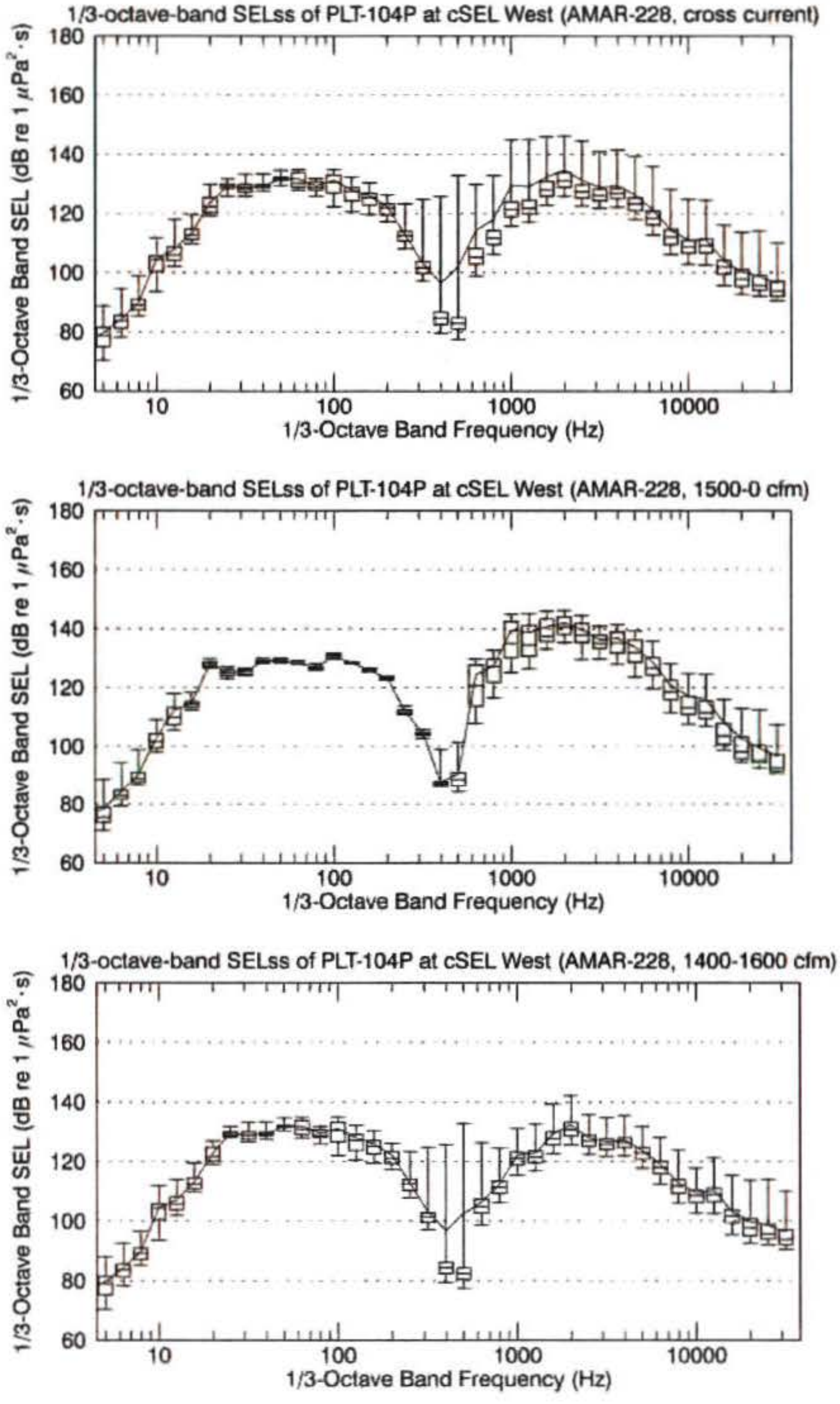



Figure 9. Distribution of 1/3-octave SELss for the pile driving of Test Pile PLT-104P measured 201 ft from the pile at location cSEL West using AMAR-228. . Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$). Top: All NAS settings (1863 strikes). Middle: 135-0 psi (1500–0 cfm, 151 strikes). Bottom: NAS at 55-70 psi (1400–1600 cfm, 1712 strikes).

Table 13. Sound levels for the pile driving of Test Pile PLT-104P measured 201 ft from the pile at location cSEL West using AMAR-228.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 180.0** | 160.3 | 152.6 |
| $L_5$ | 169.9 | 152.7 | 145.4 |
| $L_{25}$ | 164.6 | 148.2 | 142.0 |
| $L_{50}$ | 162.9 | 147.1 | 141.0 |
| $L_{75}$ | 161.4 | 146.1 | 139.9 |
| $L_{95}$ | 159.2 | 145.1 | 139.1 |
| $L_{mean}$ | 166.0 | 149.3 | 142.5 |

*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 ($L_{50}$).

**The valves from the NAS air-compressors to the air tanks were off from 11:08-11:11, which caused the air volume delivered to the bubble rings to drop from 135 to 0 psi (1500 to 0 cfm). Sound levels rose over this time period and returned to their expected levels at 11:12 when the NAS operation returned to normal

## A.3. Impact Pile-Driving Sound Levels rms SPL West

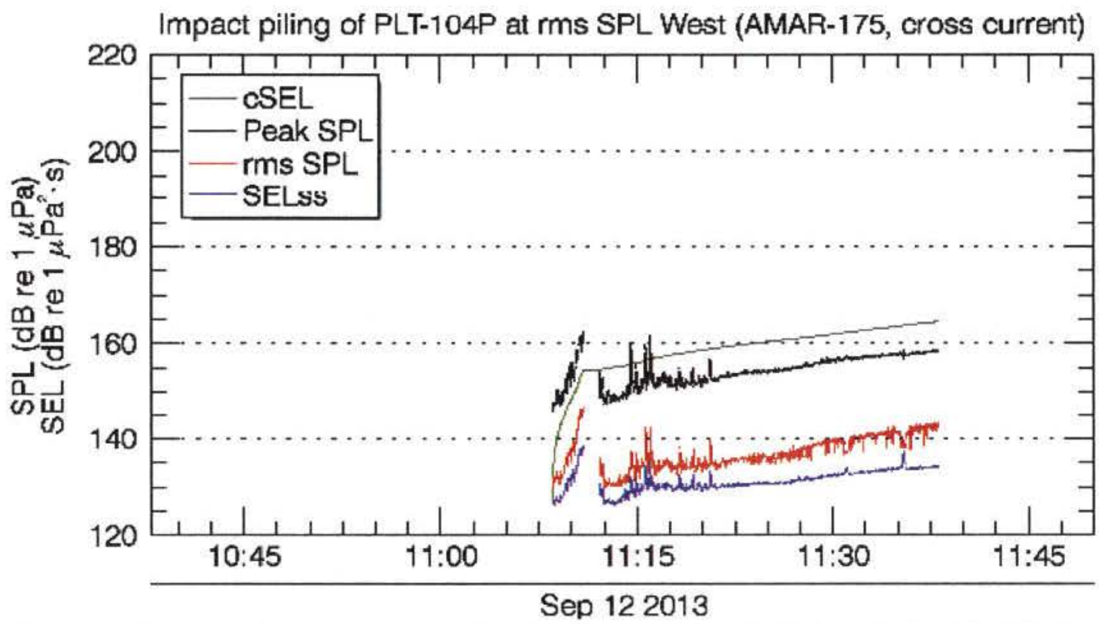



Figure 10. *Impact Pile Driving*: Peak and rms SPL, SELss, and cSEL versus time (EDT) for the pile driving of Test Pile PLT-104P measured 507 ft from the pile at location rms SPL West using AMAR-175. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time. The valves from the NAS air-compressors to the air tanks were off from 11:08-11:11, which caused the air volume delivered to the bubble rings to drop from 135 to 0 psi (1500 to 0 cfm). Sound levels rose over this time period and returned to their expected levels at 11:12 when the NAS operation returned to normal.

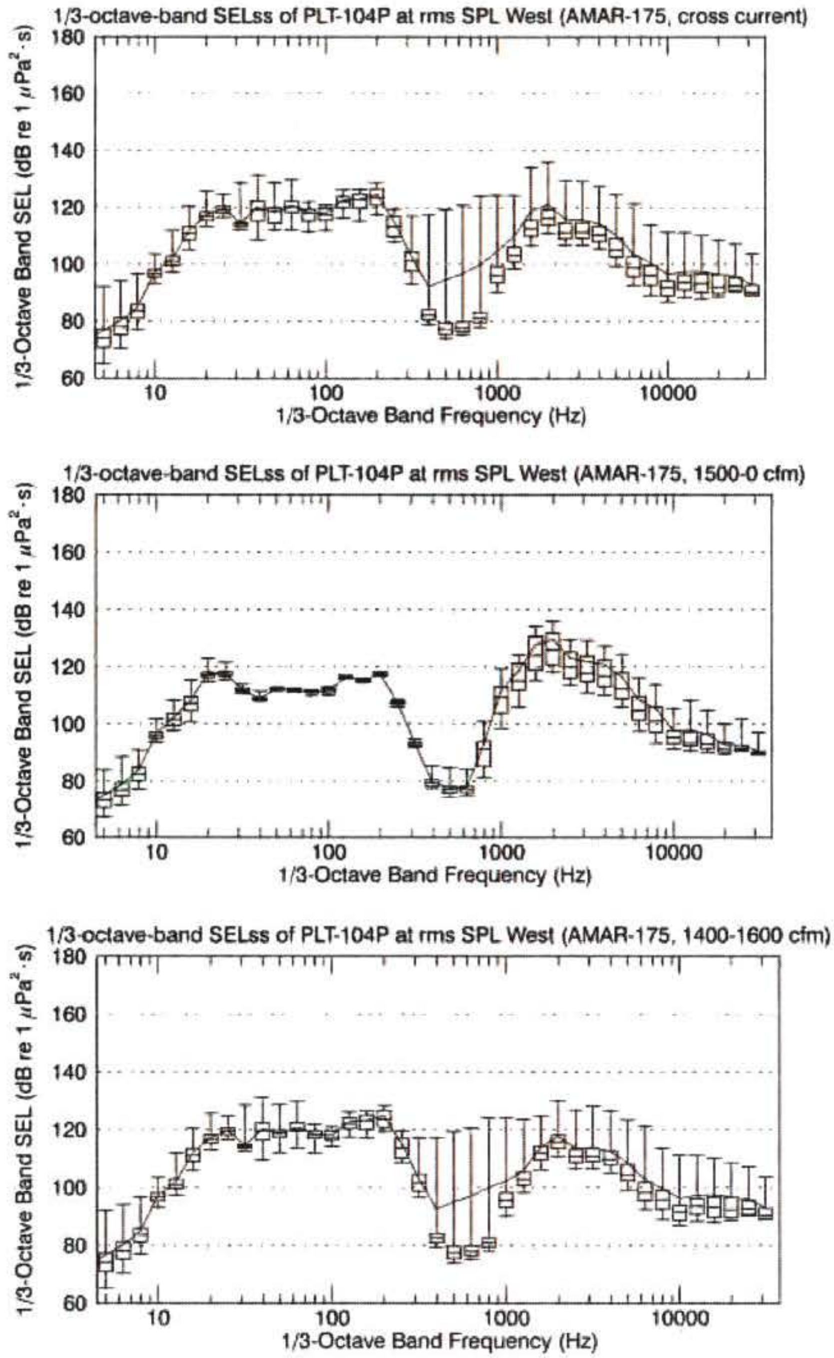



Figure 11. Distribution of 1/3-octave SELss for the pile driving of Test Pile PLT-104P measured 507 ft from the pile at location rms SPL West using AMAR-175. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$). Top: All NAS settings (1863 strikes). Middle: 135-0 psi (1500–0 cfm, 151 strikes). Bottom: NAS at 55-70 psi (1400–1600 cfm, 1712 strikes).

Table 14. Sound levels for the pile driving of Test Pile PLT-104P measured 507 ft from the pile at location rms SPL West using AMAR-175.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 164.9** | 147.5 | 139.6 |
| $L_5$ | 158.3 | 142.8 | 134.2 |
| $L_{25}$ | 157.1 | 140.0 | 133.1 |
| $L_{50}$ | 154.5 | 136.5 | 131.0 |
| $L_{75}$ | 152.4 | 134.7 | 130.0 |
| $L_{95}$ | 148.8 | 131.2 | 127.2 |
| $L_{mean}$ | 155.5 | 138.6 | 132.0 |

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

** The valves from the NAS air-compressors to the air tanks were off from 11:08-11:11, which caused the air volume delivered to the bubble rings to drop from 135 to 0 psi (1500 to 0 cfm). Sound levels rose over this time period and returned to their expected levels at 11:12 when the NAS operation returned to normal

JASCO APPLIED SCIENCES

# Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 104 Installation

**Daily Memorandum for 18 September 2013**

*Submitted to:*

[redacted]


*Authors:*

[redacted]

JASCO Applied Sciences

[redacted]


03 January 2014

P001206-001

# 1. Summary

## 1.1. Pile Location and Monitoring Summary

Test Pile PLT-104 is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 18 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 during test pile installation (Figure 1, Table 2). Pile driving occurred between 16:20–17:50 Eastern Daylight Time (EDT), and full ebb tide occurred at 15:53 EDT, slowing to slack tide at 18:44 EDT.

One period of pile driving occurred with 0.6 knot current (16:20-16:45) and a second at near slack current (17:20-17:40). Breaks often occurred during test pile installation and vary between test piles. The breaks were generally due to transfer of pile equipment and marking test piles during installation.

Table 1. Summary of Test Pile PLT-104 activities, 18 September 2013.

| | |
|---|---|
| Date: | 18 September 2013 |
| ***Pile-Driving Activity*** | |
| Test pile identifier: | PLT-104 |
| Pile diameter: | [redacted] |
| Water depth: | 9 ft |
| Hammer type: | Impact (IHC S-280) |
| Total hammer strikes: | 2343 |
| Total penetration: | 339 ft |
| Net duration of pile driving (hh:mm:ss): | 00:25:48 |
| Maximum single strike energy: | 124 thousand foot-pounds (kip-ft), (169 kJ) |
| Total energy transferred: | 279,083 kip-ft (378 MJ) |
| ***Noise Attenuation System (NAS)*** | |
| Single-tier unconfined bubble curtain airflow rate: | 1300–1425 cubic feet per minute (cfm), 55–57 pounds per square inch (psi) |
| River conditions during pile driving: | Ebb to slack tide, 0–1.0 knots (0–0.5 meters per second [m/s] depth dependent ; Table 6, and Figure 5) |

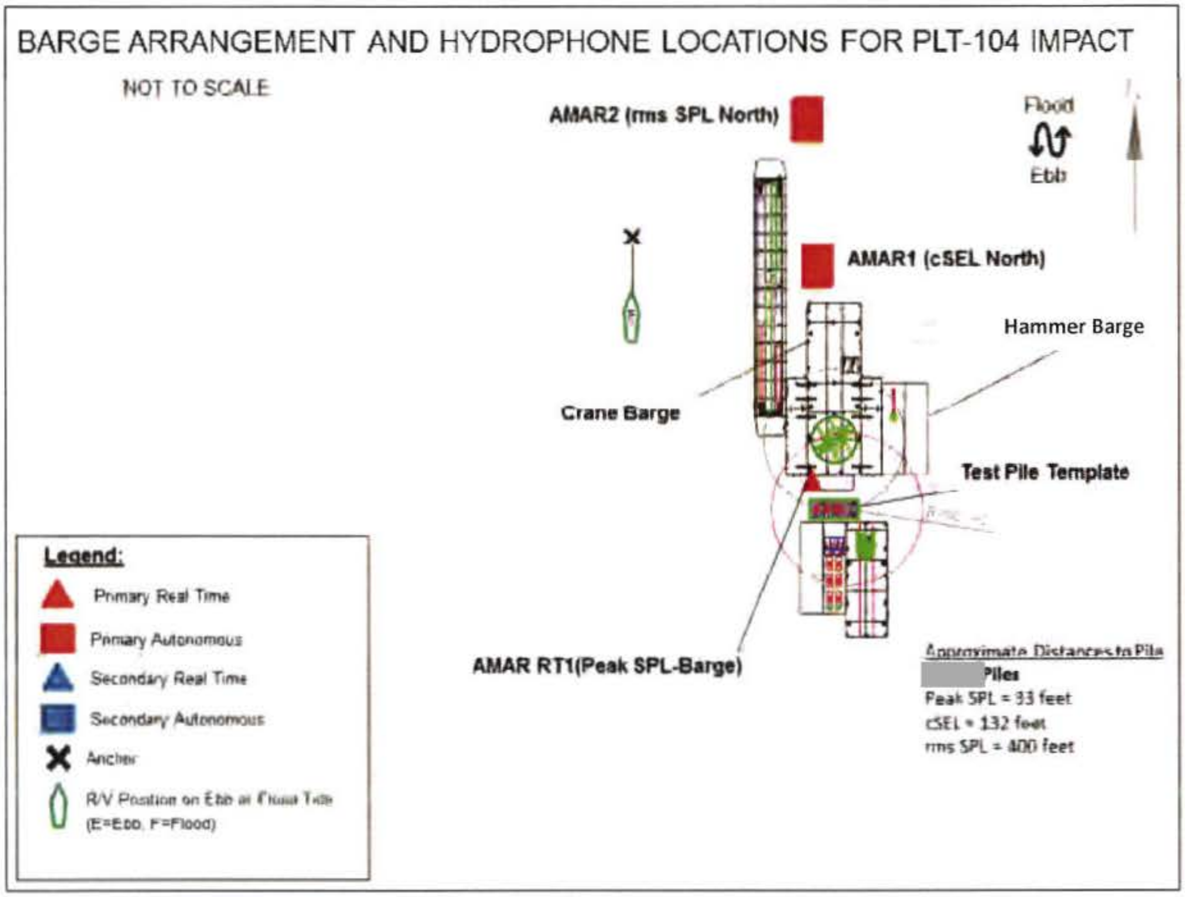



Figure 1. Plan view of pile and barge layout, 18 September 2013, Test Pile PLT-104.

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

| Location | AMAR ID | Distance to pile (ft) | Water depth (ft) | Max peak SPL (dB re 1 μPa) | cSEL (dB re 1 $\mu Pa^2 \cdot s$)* |
|---|---|---|---|---|---|
| Peak SPL Barge (up current) | AMAR-RT11 | 32 | 9 | 200 | 198 |
| cSEL North (up current) | AMAR-175 | 184 | 9 | 173 | 177 |
| rms SPL North (up current | AMAR-228 | 575 | 9 | 157 | 162 |

*Calculated by multiplying the average SELss by the number of strikes reported by the pile driving contractor.

## 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 $\mu Pa^2 \cdot s$ cumulative sound exposure level (cSEL) isopleth was estimated to be 156 ft at the end of pile driving. Since cSEL increases as the number of strikes increases, the diameter of the 187 dB isopleth was smaller than 156 ft for most of the pile driving operation.. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

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

| Criteria | Estimated mean diameter (ft) |
|---|---|
| 206 dB re 1 μPa peak SPL | 19 |
| 187 dB re 1 $\mu Pa^2 \cdot s$ cSEL | 156* |
| 150 dB re 1 μPa rms SPL (1 s integration time) | 386 |

* At the end of pile driving

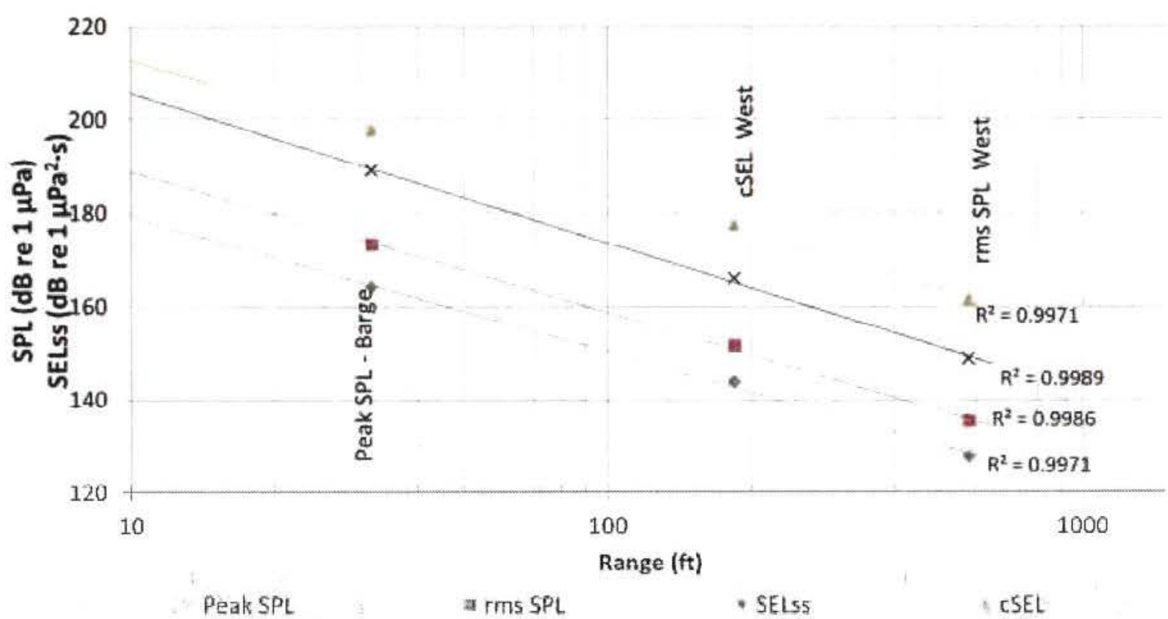



Figure 2. Regression based on mean values of the peak SPL, rms SPL, SELss, and cSEL from each recorder from pile driving of Test Pile PLT-104, 18 September 2013. SELss, Peak SPL, and rms SPL are instantaneous values. The cSEL represents the total sound energy measured during the pile driving.

### 1.3. Observations

The hammer energy was nearly constant at 120±5 kip-ft (Figure 4) throughout the pile driving at PLT-104. Similarly the NAS air pressure and airflow were nearly constant (Table 5). The currents dropped from an approximate average of 0.6 knots to slack current (Figure 5), with one extended period of pile driving at 0.6 knots (16:20-16:48), and a second at near slack current (17:20-17:50). There was no observable effect on the measured sound levels from the change in current (Figure 3).

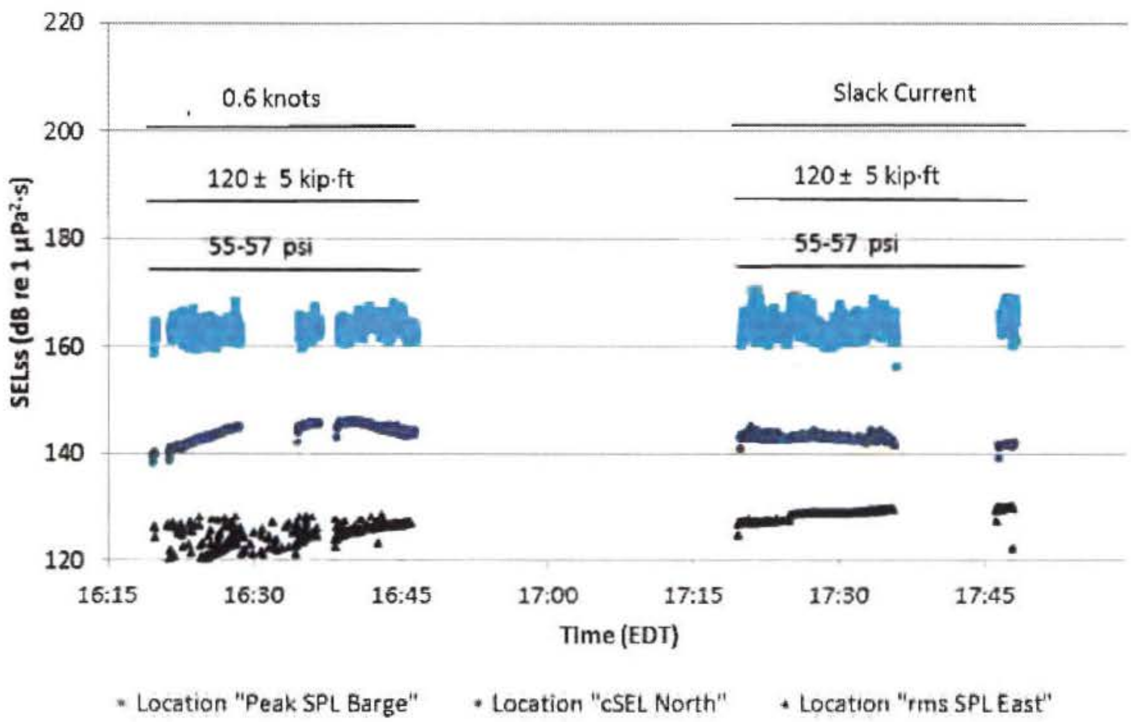



Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

## 2. Activity Logs

### 2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 18 September 2013.

Table 4. JASCO and construction activities for 18 September 2013.

| Time (EDT) | Activity |
|---|---|
| 07:50 | Arrive at dock, prep recorders |
| 08:40 | Leave dock for job site |
| 09:00 | On standby; attempt to grapple for lost recorders |

| | |
|---|---|
| 15:30 | Transfer to barge, deploy AMAR-175 |
| 15:40 | Deploy AMAR-RT from barge and AMAR-228 from Alpine vessel |
| 16:20 | Start pile driving |
| 17:50 | Stop pile driving |
| 17:55 | Begin retrieving recorders |
| 19:00 | All work complete. |

## 2.2. Pile Driving Logs

### 2.2.1. NAS

NAS used: Single-tier unconfined bubble curtain

NAS settings: 1300–1425 cfm, 55–57 psi

Table 5. NAS setting recorded during pile driving at Test Pile PLT-104, 18 September 2013.

| Time (EDT) | Volume/min (cfm) | Pressure (psi) |
|---|---|---|
| 16:19 | 1300–1350 | 55 |
| 16:35 | 1300–1350 | 55 |
| 16:38 | 1375–1425 | 55–57 |
| 17:20 | 1350–1400 | 55 |
| 17:46 | 1300–1325 | 55 |

### 2.2.2. Impact Hammering Log

Total energy: 279,083 kip-ft (378 MJ)

Total number of strikes: 2343

Maximum per-strike energy: 124 kip-ft (169kJ)

Net pile driving duration (hh:mm:ss): 00:25:48

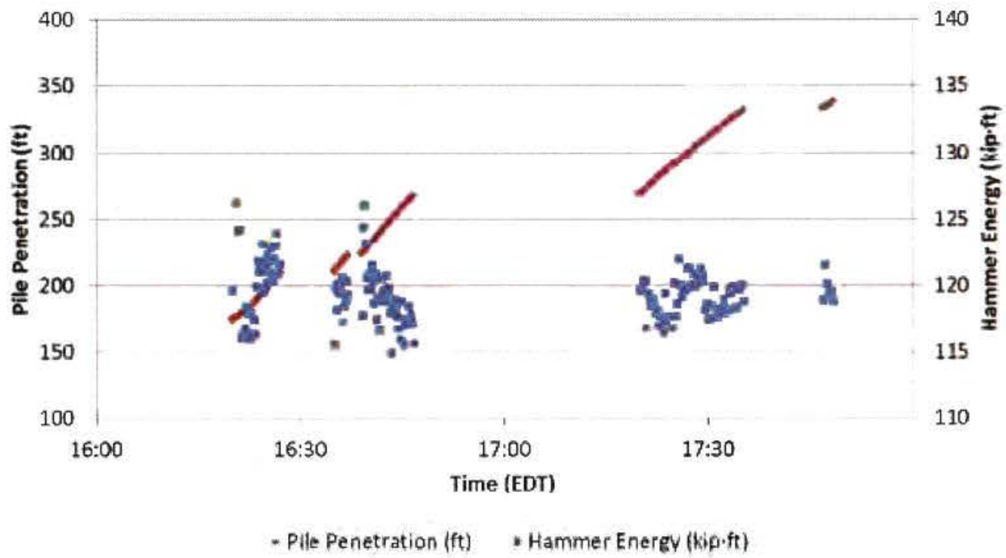



Figure 4. Hammer energy (kip-ft) and pile penetration (ft) during pile driving of PLT-104, 18 September 2013.

# 3. Weather and River Conditions

Table 6 provides the predicted currents at the project site on 18 September 2013. Figure 5 provides the Acoustic Doppler Current Profiler (ADCP)-measured currents. Figure 6 provides the speed of sound in water, based on salinity and temperature, measured using the conductivity, temperature, depth (CTD) cast.

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

| | |
|---|---|
| Weather conditions: | Sunny, ~5 knot southerly wind |
| Full ebb current: | 15:53 (2.4 knots) |
| Slack current: | 12:12, 18:44 |
| Full flood current: | 09:25 (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=

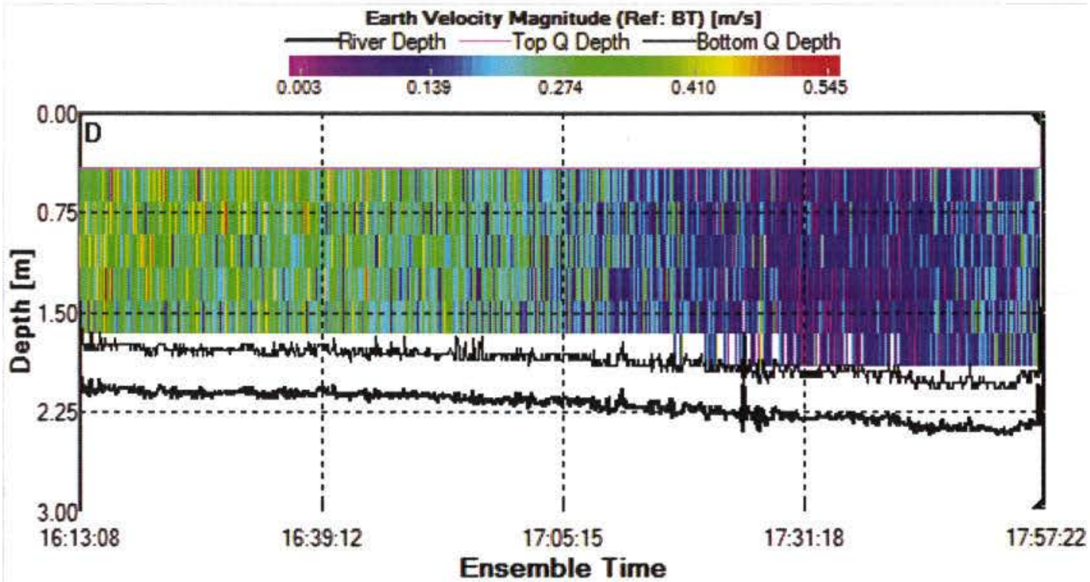



Figure 5. ADCP data from 18 September 2013 from the Alpine vessel, located 575 ft from the pile. Times are in EDT.

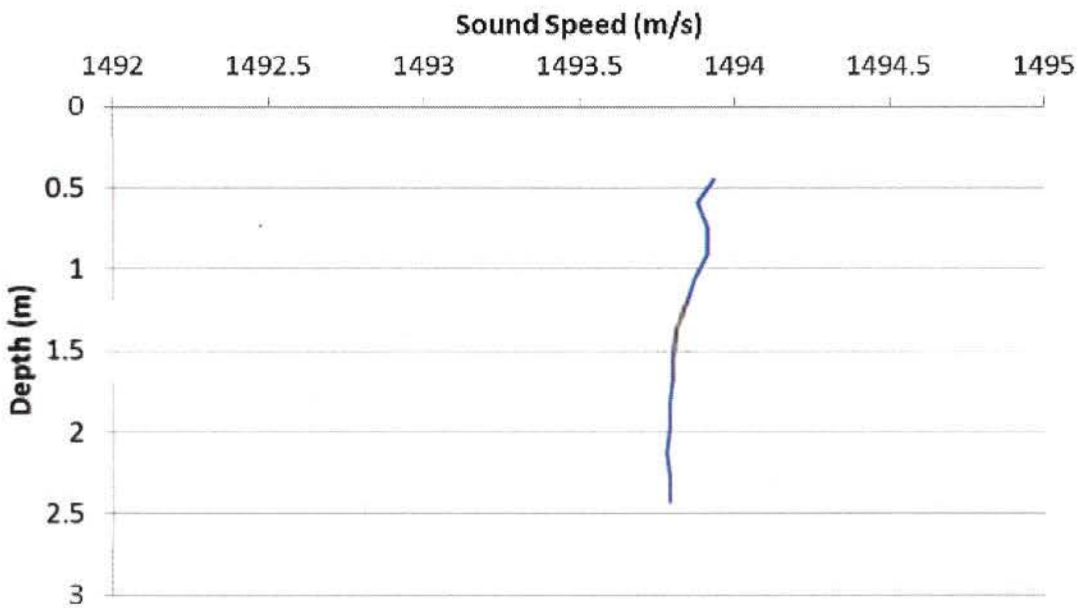



Figure 6. CTD cast performed at 18:05 EDT from the Alpine vessel, located 575 ft from the pile.

# 4. Monitoring Equipment

## 4.1. Real-time Monitoring Equipment

Table 7 provides information on the real-time monitoring equipment used on 18 September 2013. Table 8 provides location information on the real-time recorders.

Table 7. Real-time monitoring equipment for Test Pile PTL-104, 18 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 8. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 18 September 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time (EDT) | Water depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| Peak SPL Barge | AMAR-RT11 | 41.07132 | 73.9127 | 15:40 | 9 | 32 |

## 4.2. Autonomous Monitoring Equipment

Table 9 provides information about the autonomous monitoring equipment used on 18 September 2013. Table 10 provides the locations of the autonomous recorders.

Table 9. Autonomous recording equipment for Test Pile PTL-104, 18 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: | -200.1 dB re 1 V/µPa | 1 |
| AMAR-175 Sensitivity: | -200.1 dB re 1 V/µPa | 1 |

Table 10. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 18 September 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time (EDT) | Water depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| cSEL North (up current) | AMAR-175 | 41.07164 | -73.91235 | 15:30 | 9 | 184 |
| rms SPL North (up current) | AMAR-228 | 41.07268 | -73.91192 | 15:40 | 9 | 575 |

# Appendix A. Pile Driving Plots

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

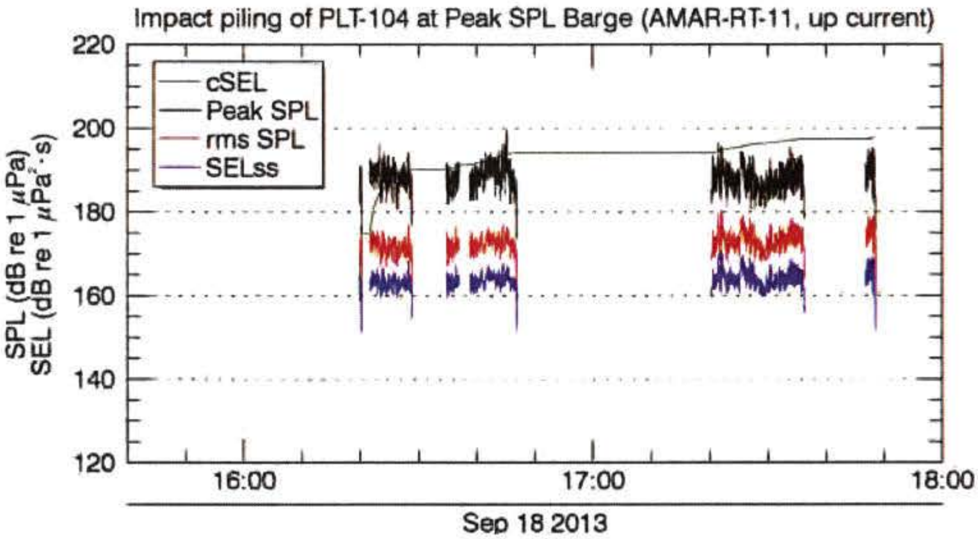



Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL for the pile driving of Test Pile PLT-104 measured 32 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

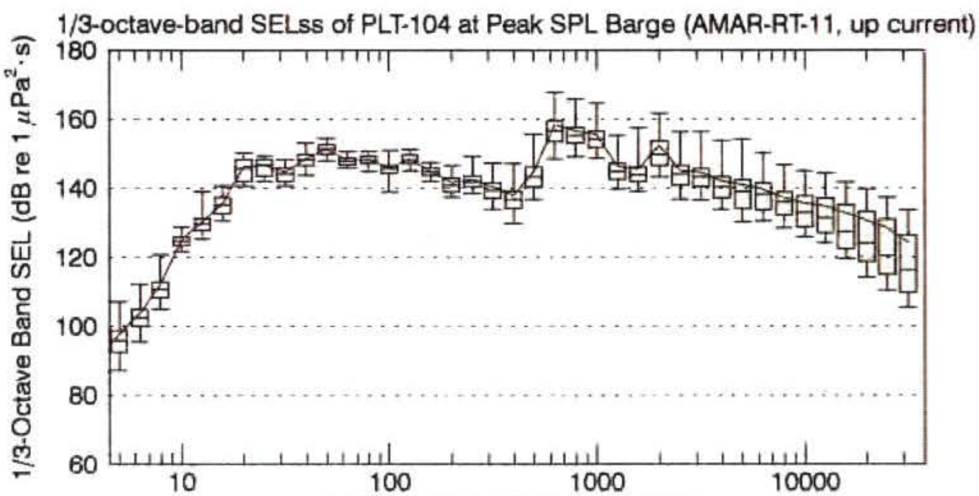



Figure 8. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-104 measured 32 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 11. Sound levels for the pile driving of Test Pile PLT-104 measured 32 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 199.7 | 180.2 | 170.7 |
| $L_5$ | 192.7 | 176.5 | 166.9 |
| $L_{25}$ | 190.3 | 173.9 | 164.7 |
| $L_{50}$ | 188.3 | 172.5 | 163.5 |
| $L_{75}$ | 186.3 | 171.2 | 162.4 |
| $L_{95}$ | 183.5 | 169.3 | 161.0 |
| $L_{mean}$ | 189.1 | 173.2 | 164.0 |

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

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

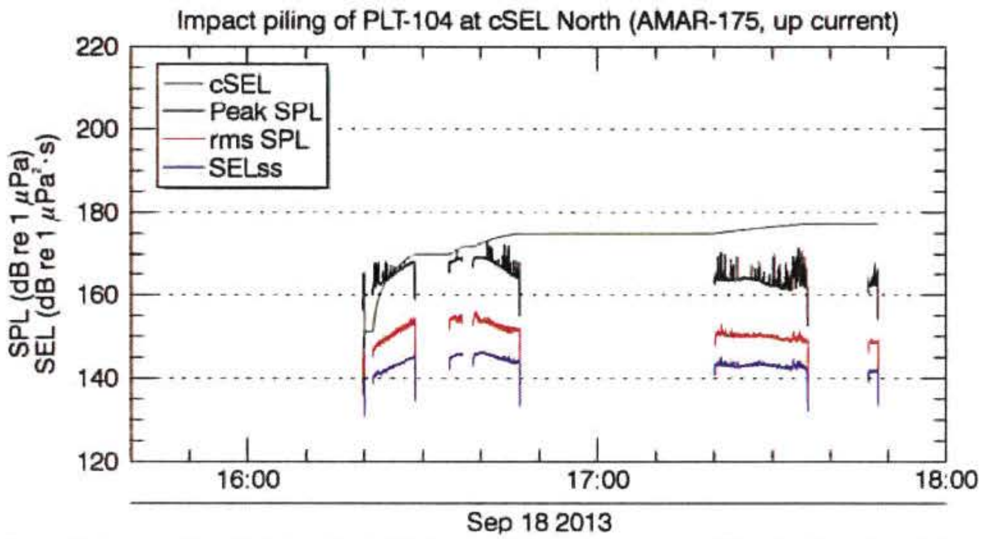



Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, SELss, and cSEL for the pile driving of Test Pile PLT-104 measured 184 ft from the pile at location cSEL North on AMAR-175. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

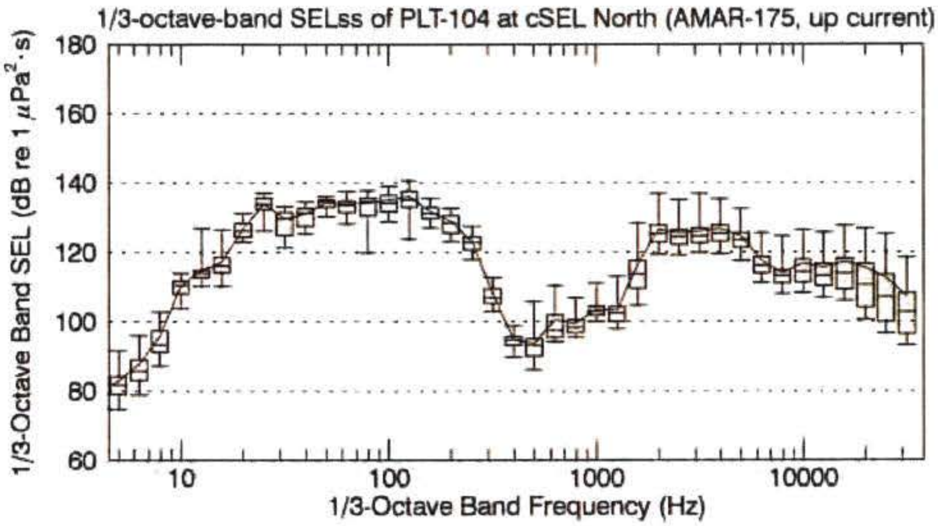



Figure 10. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-104 measured 184 ft from the pile at location cSEL North on AMAR-175. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). 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-104 measured 184 ft from the pile at location cSEL North on AMAR-175.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 173.1 | 156.0 | 146.2 |
| $L_5$ | 168.9 | 154.3 | 145.8 |
| $L_{25}$ | 167.3 | 152.2 | 144.5 |
| $L_{50}$ | 164.5 | 150.5 | 143.3 |
| $L_{75}$ | 163.5 | 149.6 | 142.7 |
| $L_{95}$ | 161.9 | 148.4 | 141.4 |
| $L_{mean}$ | 165.8 | 151.4 | 143.7 |

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

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

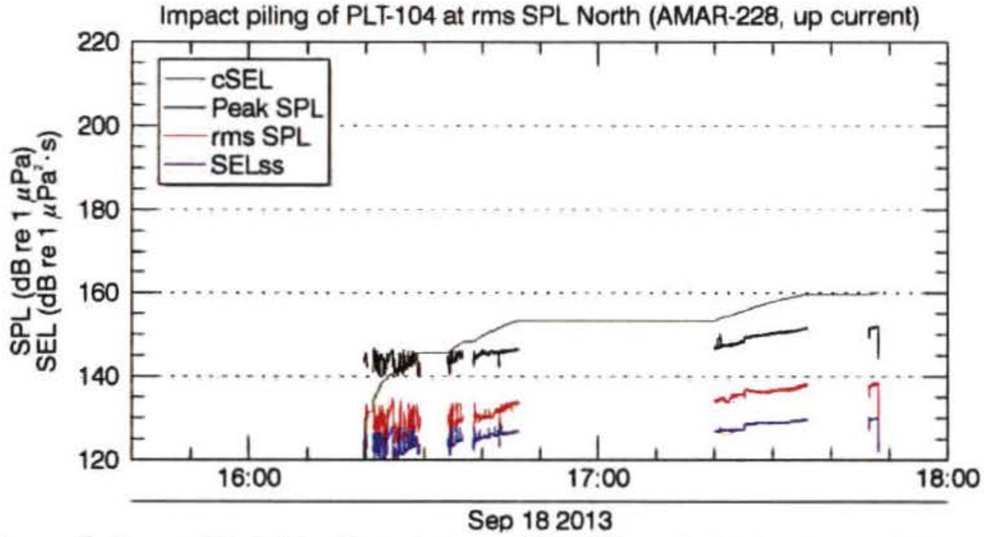



Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SEL, and cSEL for the pile driving of Test Pile PLT-104 measured 575 ft from the pile at location rms SPL North using AMAR-228. . For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

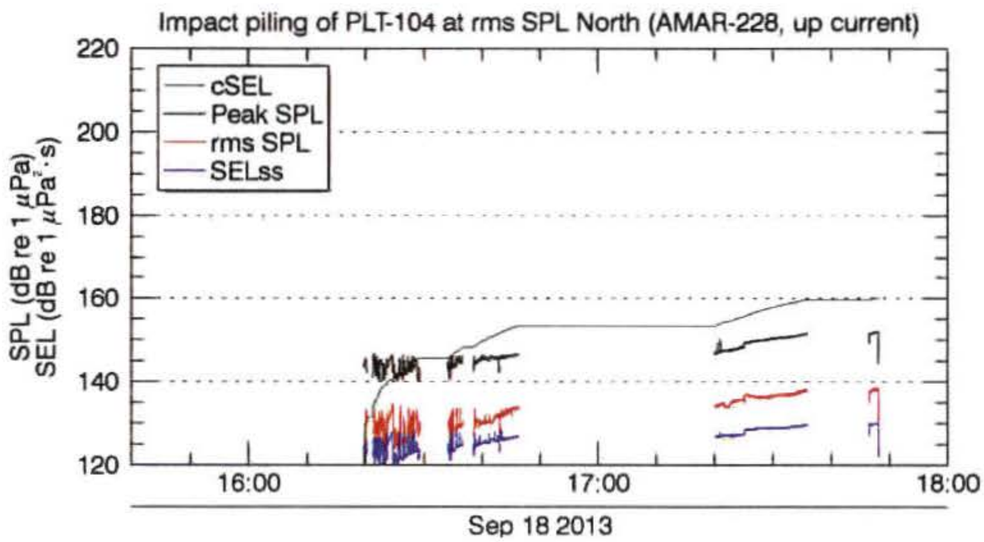



Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-104 measured 575 ft from the pile at location rms SPL North using AMAR-228. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). 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-104 measured 575 ft from the pile at location rms SPL North using AMAR-228.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 157.0 | 147.7 | 137.9 |
| $L_5$ | 151.9 | 139.8 | 131.8 |
| $L_{25}$ | 150.5 | 136.8 | 129.0 |
| $L_{50}$ | 148.0 | 135.1 | 127.4 |
| $L_{75}$ | 145.8 | 131.4 | 126.0 |
| $L_{95}$ | 141.9 | 125.5 | 121.6 |
| $L_{mean}$ | 149.0 | 135.9 | 128.3 |

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

JASCO
APPLIED SCIENCES

# Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 105 Installation

**Daily Memorandum for 15 October 2013**

*Submitted to:*

[redacted]


*Authors:*

[redacted]

JASCO Applied Sciences

[redacted]


03 January 2014

P001206-001

# 1. Summary

## 1.1. Pile Location and Monitoring Summary

Test Pile PLT-105 is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 15 October 2013 (Table 1). One real-time acoustic monitoring system and two autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors, LLC (TZC) (Figure 1 and Table 2). Pile driving occurred 14:46–15:24 Eastern Daylight Time (EDT). Full ebb tide occurred at 13:49 and slack current occurred at 16:41 EDT.

Table 1. Summary of Test Pile PLT-105 activities,15 October 2013.

| | |
|---|---|
| Date: | 15 October 2013 |
| ***Pile-Driving Activity*** | |
| Test pile identifier: | PLT-105 |
| Pile diameter: | [redacted] |
| Water depth: | 13 ft |
| Hammer type: | Impact (IHC S-280) |
| Total hammer strikes: | 2059 |
| Total penetration: | 337 ft |
| Net duration of pile driving (hh:mm:ss): | 00:20:04 |
| Maximum single strike energy: | 127 thousand foot-pounds (kip-ft), (172 kJ) |
| Total energy transferred: | 25,3072 kip-ft (343 MJ) |
| ***Noise Attenuation System (NAS)*** | |
| Two-tier unconfined bubble curtain airflow rate: | 1700–1800 cubic feet per minute (cfm), 65 pounds per square inch (psi) |
| River conditions during pile driving: | Ebb tide, 0.5–0.7 knots (0.25–0.35 meters per second [m/s], depth dependent; Table 5, Figure 6) |

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

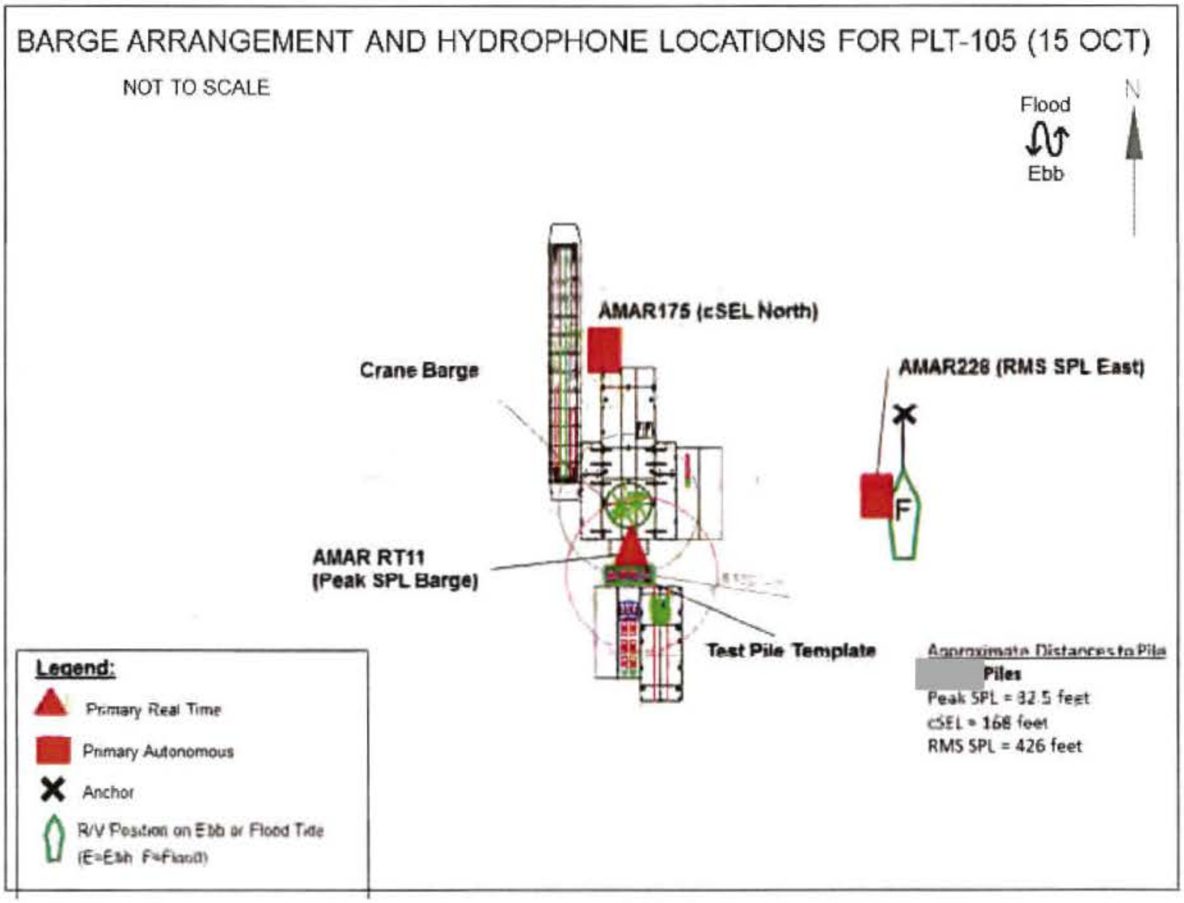



Figure 1. Plan view of pile and barge layout, 15 October 2013, Test Pile PLT-105.

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 $\mu Pa^2 s$)* |
|---|---|---|---|---|---|
| Peak SPL Barge (up current) | AMAR-RT-11 | 33 | 13 | 185 | 196 |
| cSEL North (up current) | AMAR-175 | 167 | 13 | 171 | 180 |
| rms SPL East (cross current) | AMAR-228 | 427 | 12 | 165 | 170 |

*Calculated by multiplying the average SELss by the number of strikes reported by the pile driving contractor. .

## 1.2. NMFS Physiological and Behavioral Thresholds

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

The regression indicates that the estimated diameter of the 206 dB re 1 μPa peak SPL isopleth was less than 6 ft, and did not exceed NMFS criteria of a diameter of 40 ft for [redacted] piles. The diameter of the 187 dB re 1 $\mu Pa^2 \cdot s$ cumulative sound exposure level (cSEL) isopleth was estimated to be 164 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 164 ft for most of the pile driving operation. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

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

| Criteria | Estimated mean diameter (ft) |
|---|---|
| 206 dB re 1 μPa peak SPL | < 6 |
| 187 dB re 1 $\mu Pa^2 \cdot s$ cSEL* | 164 |
| 150 dB re 1 μPa rms SPL (1 s integration time) | 584 |

*At the end of pile driving

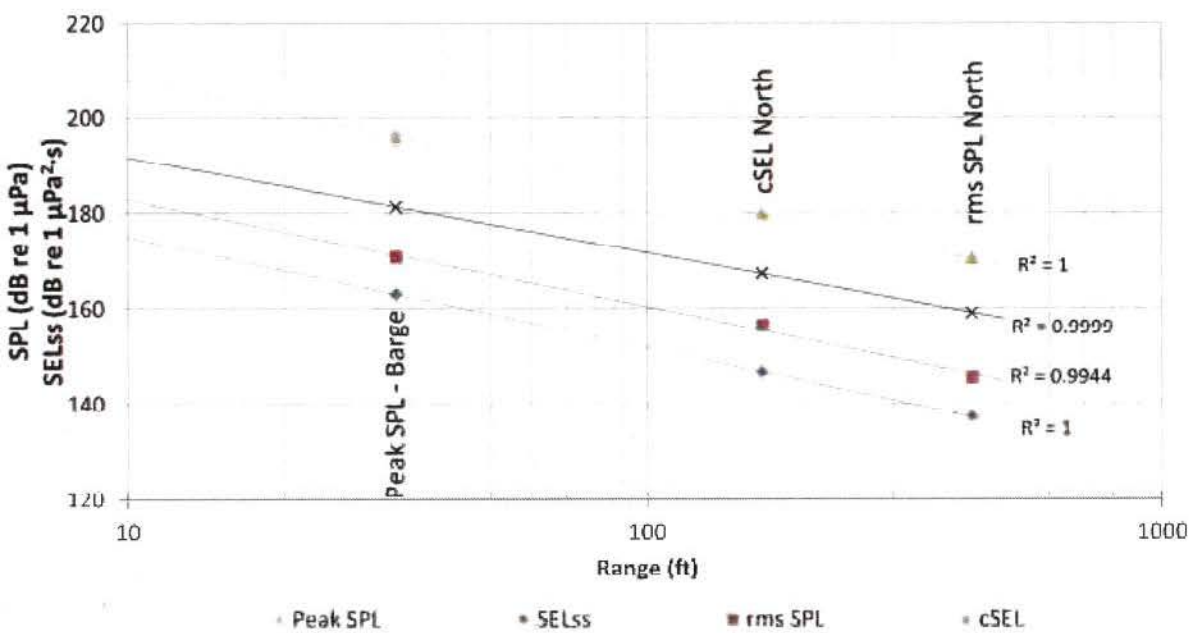



Figure 2. Regression based on mean values of the peak SPL, rms SPL, SELss and cSEL from each recorder from pile driving of Test Pile PLT-105, 15 October 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents the total sound energy measured during the pile driving.

### 1.3. Observations

The hammer energy during pile driving at PLT-105 was nearly constant at 122 ± 6 kip-ft (Figure 3, Figure 4). Similarly the NAS air pressure and airflow were constant at 65 psi and 1750–1800 cfm (Figure 3). The majority of the pile driving occurred during the ebb tide, with an approximate average current of 0.5 to 0.7 knots (Figure 3, Figure 6). Pile driving concluded near the end of the end tide, when the current reduced from approximately 0.4 to 0.1 knots. However, there was no observable effect on the measured sound (Figure 3). While variations in sound levels at the three measurement locations were qualitatively different (Figure 3), there was no effect on meeting NMFS or NYSDEC physiological or behavioral thresholds (Figure 2).

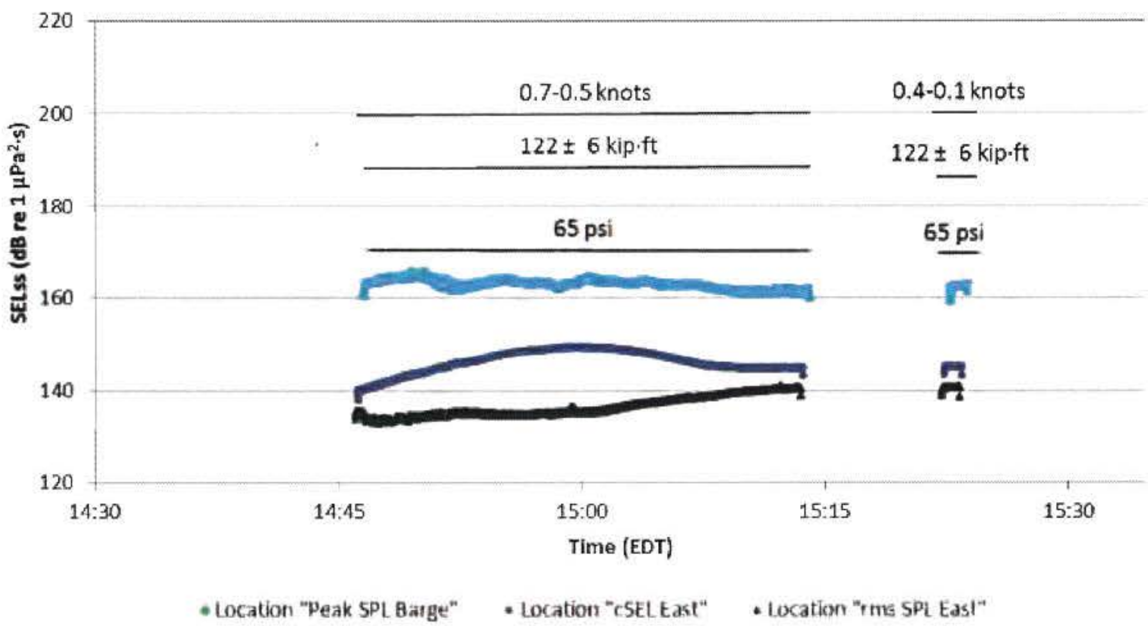



Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

## 2. Activity Logs

### 2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 15 October 2013.

Table 4. JASCO and construction activities for Test Pile PLT-105, 15 October 2013.

| Time (EDT) | Activity |
|---|---|
| 05:55 | Arrive at dock, prep recorders |
| 06:30 | Leave dock for job site; instructed to stand-by on arrival |
| 10:00 | Start deployment of recorders |

| | |
|---|---|
| 10:33 | Deployment complete |
| 11:35 | Begin lifting hammer |
| 12:21 | Start pile driving of PLT-105P |
| 13:02 | Stop pile driving of PLT-105P, standby for PLT-105 |
| 14:46 | Start pile driving of PLT-105 |
| 15:24 | Stop pile driving of PLT-105; begin retrieval |
| 15:40 | Retrieval complete, en route to dock |
| 16:30 | All work complete. |

## 2.2. Pile Driving Logs

### 2.2.1. NAS

NAS used: Two-tier unconfined bubble curtain

NAS settings: 1700–1800 cfm, 65 psi

### 2.2.2. Impact Hammering Log

Total energy: 253,072 kip-ft (343 MJ)

Total number of strikes: 2059

Maximum per-strike energy: 126.5 kip-ft (172 kJ)

Net pile driving duration (hh:mm:ss): 00:20:04

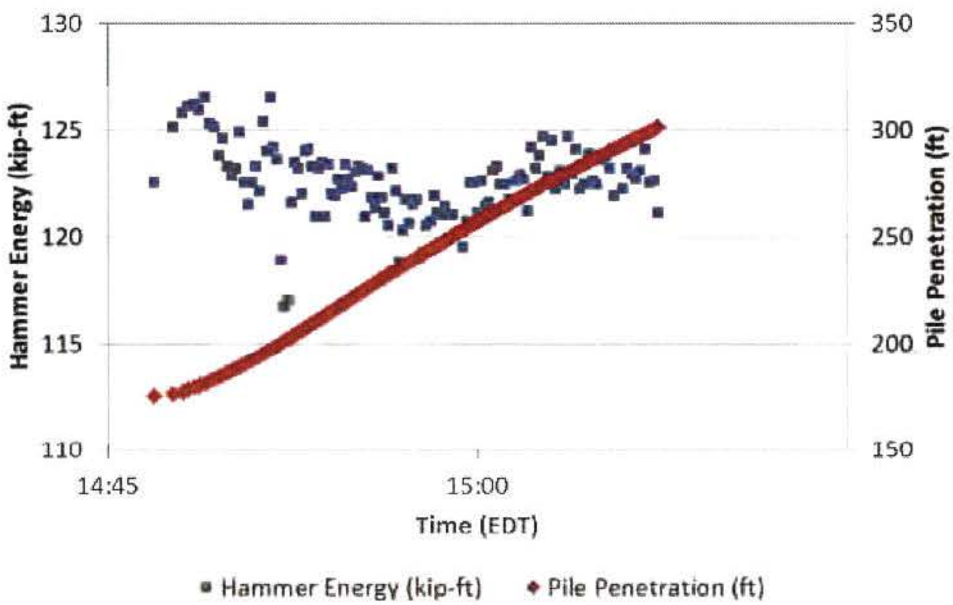



Figure 4. Hammer energy (kip-ft) and pile penetration (ft) during pile driving of PLT-105, 15 October 2013.

# 3. Weather and River Conditions

Table 5 provides the predicted currents at the project site on 15 October 2013. Figure 5 provides the speed of sound in water, based on salinity and temperature measured, using the conductivity, temperature, depth (CTD) cast. Figure 6 provides the currents measured at the project site on 15 October using an Acoustic Doppler Current Profiler (ADCP).

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

| | |
|---|---|
| Weather conditions: | Sunny, light winds |
| Full ebb current: | 13:49 (−2.2 knots) |
| Slack current: | 16:41 |
| Full flood current: | n/a |

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

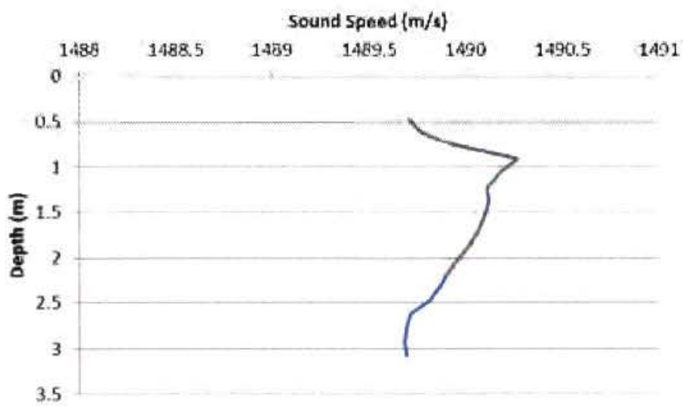



Figure 5. CTD cast performed at 12:24 EDT from the Alpine vessel, located 427 ft E of the pile (41.0707 N, 73.9022 W).

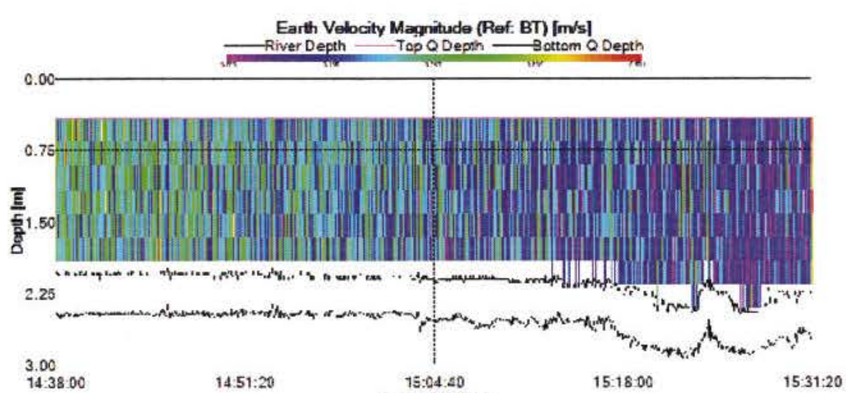



Figure 6. ADCP data from 15 October 2013 from the Alpine vessel, located 427 ft from the pile. Times are in EDT.

# 4. Monitoring Equipment

## 4.1. Real-time Monitoring Equipment

Table 6 provides information on the real-time monitoring equipment used on 15 October 2013. Table 7 provides location information on the real-time recorders.

Table 6. Real-time monitoring equipment for Test Pile PLT-105, 15 October 2013.

| Equipment used | | Units deployed |
|---|---|---|
| ***Acoustic data logger*** | | |
| Model: | AMAR RT (JASCO Applied Sciences) | 1 |
| *SpectroPlotter* version: | 6.0.1 | 1 |
| ***Hydrophone*** | | |
| Model: | M8KC (GTI) | 1 |
| AMAR-RT-11 sensitivity: | −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 7. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 15 October 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time (EDT) | Water depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| Peak SPL Barge (up current) | AMAR-RT-11 | 41.07124 | 73.91025 | 14:20 | 13 | 33 |

## 4.2. Autonomous Monitoring Equipment

Table 8 provides information about the autonomous monitoring equipment used on 15 October 2013.

Table 9 provides the locations of the autonomous recorders.

Table 8. Autonomous monitoring equipment for PLT-105, 15 October 2013.

| Equipment used | | Units deployed |
|---|---|---|
| ***Acoustic data logger*** | | |
| Model: | AMAR G3 (JASCO Applied Sciences) | 2 |
| *SpectroPlotter* version: | 6.0.1 | 2 |
| ***Hydrophone*** | | |
| Model: | M8E-51-0dB (GTI) | 2 |
| AMAR-228 sensitivity: | −199.54 dB re 1 V/µPa | 1 |
| AMAR-175 sensitivity: | −200.64 dB re 1 V/µPa | 1 |

Table 9. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 15 October 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time (EDT) | Water depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| cSEL North (up current) | AMAR-175 | 41.07158 | −73.9101 | 10:00 | 13 | 167 |
| rms SPL East (cross current) | AMAR-228 | 41.0707 | −73.9088 | 10:20 | 12 | 427 |

# Appendix A. Pile Driving Plots

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

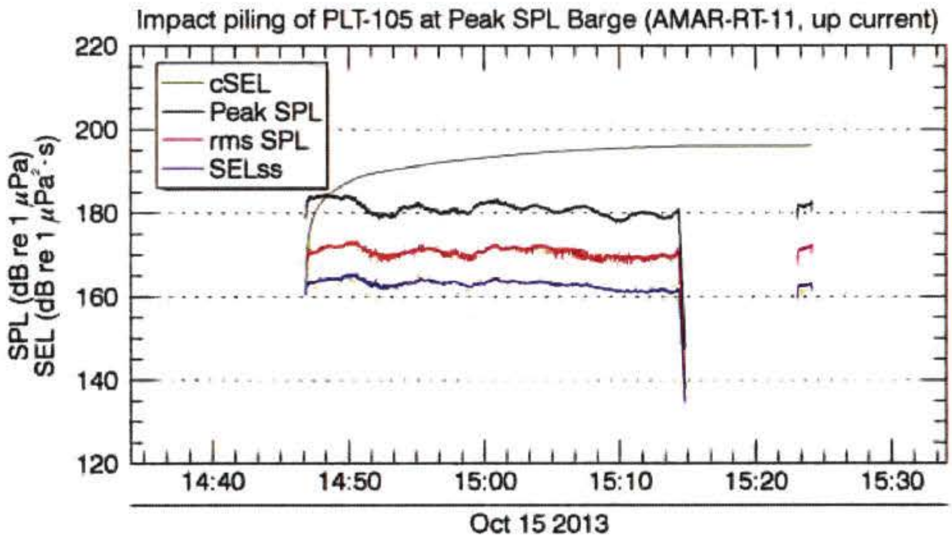



Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-105 measured 33 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

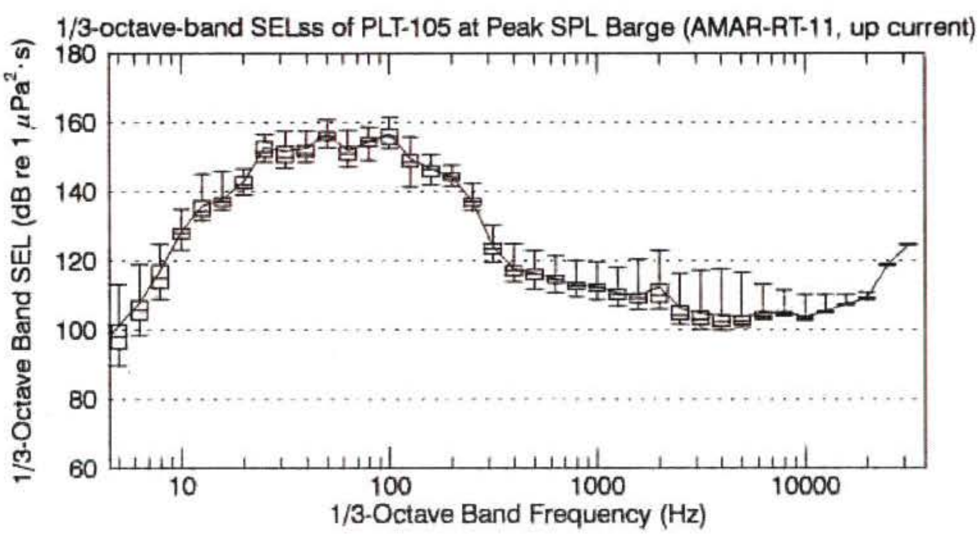



Figure 8. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-105 measured 33 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 10. Sound levels for the pile driving of Test Pile PLT-105 measured 33 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 184.5 | 173.3 | 165.6 |
| $L_5$ | 183.9 | 172.3 | 164.5 |
| $L_{25}$ | 181.9 | 171.6 | 163.5 |
| $L_{50}$ | 181.0 | 170.7 | 163.0 |
| $L_{75}$ | 179.9 | 169.7 | 162.2 |
| $L_{95}$ | 178.7 | 168.9 | 161.1 |
| $L_{mean}$ | 181.3 | 170.8 | 163;0 |

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

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

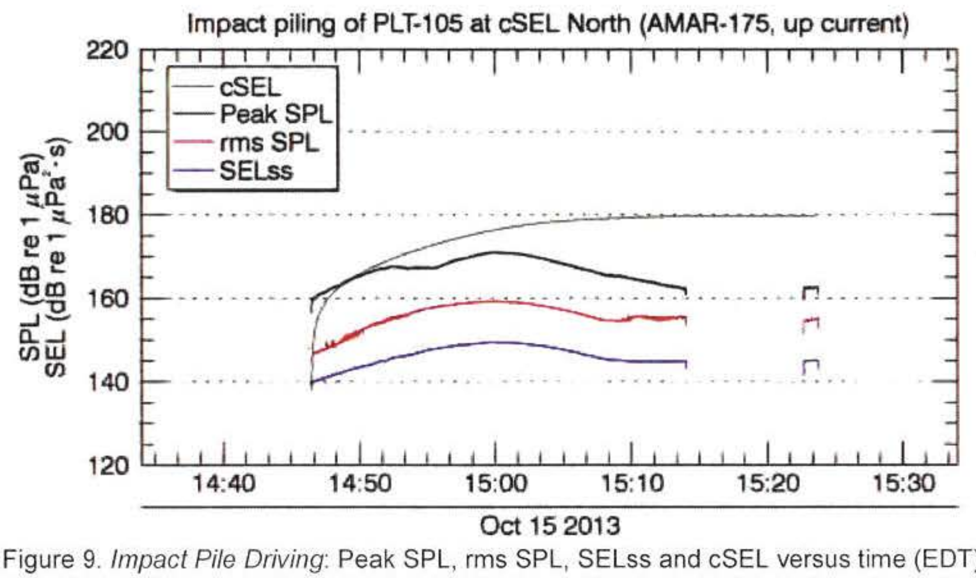



Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-105 measured 167 ft from the pile at location cSEL North using AMAR-175. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

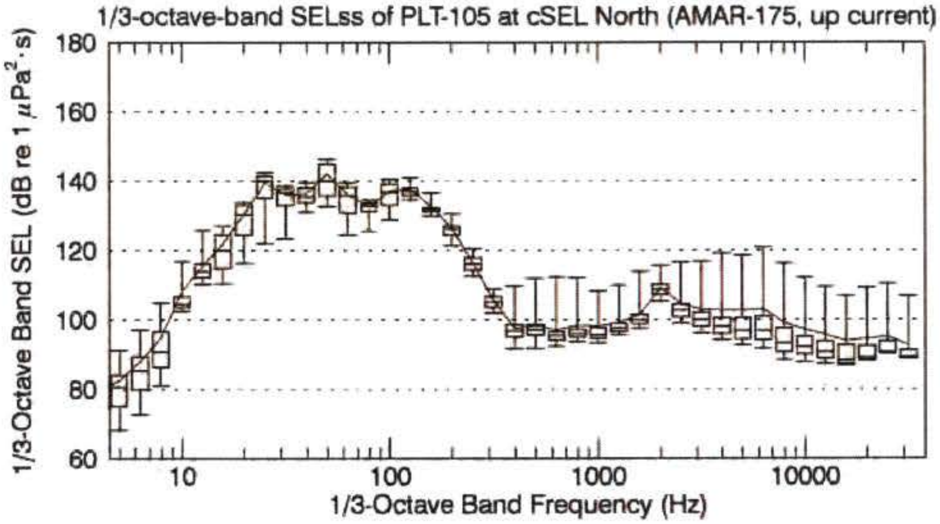



Figure 10. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-105 measured 167 ft from the pile at location cSEL North using AMAR-175. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 11. Sound levels for the pile driving of Test Pile PLT-105 measured 167 ft from the pile at location cSEL North using AMAR-175.

| Sound level statistic* | peak SPL (dB re 1 μPa) | rms SPL (dB re 1 μPa) | SELss (dB re 1 μPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 171.0 | 159.5 | 149.5 |
| $L_5$ | 170.8 | 159.1 | 149.3 |
| $L_{25}$ | 168.9 | 158.2 | 148.4 |
| $L_{50}$ | 167.1 | 155.6 | 145.9 |
| $L_{75}$ | 164.2 | 154.7 | 144.8 |
| $L_{95}$ | 162.2 | 148.5 | 141.4 |
| $L_{mean}$ | 167.4 | 156.5 | 146.7 |

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

## A.3. Impact Pile-Driving Sound Levels rms SPL East

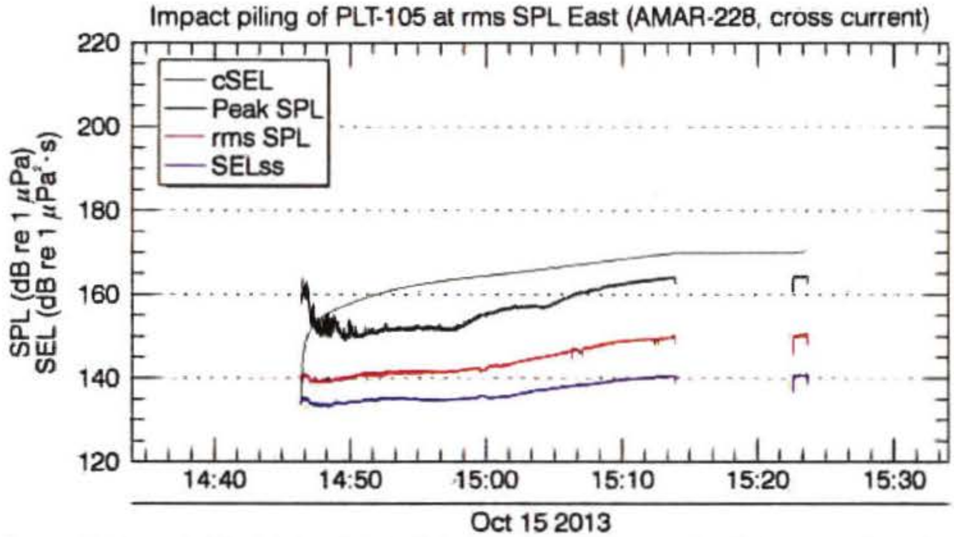



Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-105 measured 427 ft from the pile at location rms SPL East using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

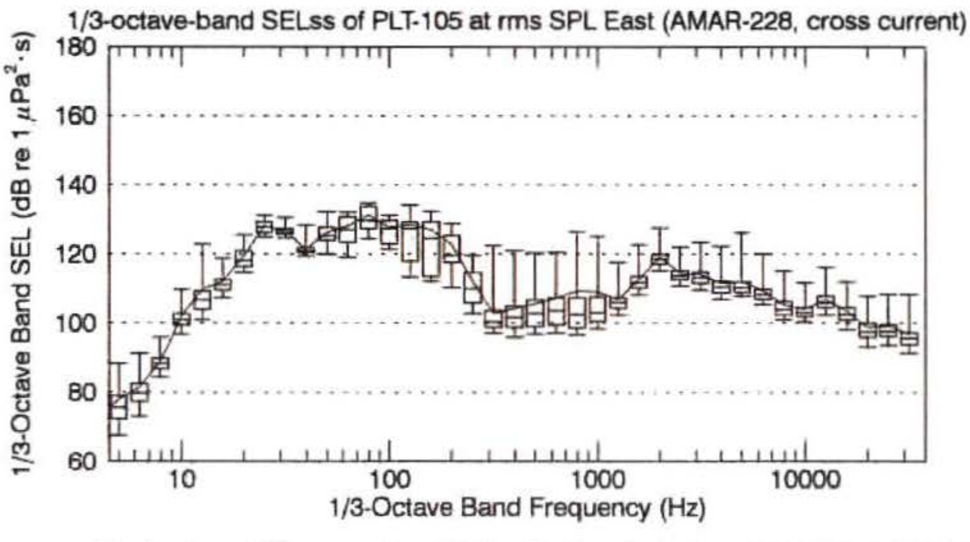



Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-105 measured 427 ft from the pile at location rms SPL East using AMAR-228. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error-bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 12. Sound levels octave for the pile driving of Test Pile PLT-105 measured 427 ft from the pile at location rms SPL East using AMAR-228.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 164.5 | 150.8 | 140.8 |
| $L_5$ | 164.0 | 149.7 | 140.5 |
| $L_{25}$ | 161.2 | 147.7 | 138.7 |
| $L_{50}$ | 156.6 | 143.0 | 135.5 |
| $L_{75}$ | 151.9 | 141.4 | 134.9 |
| $L_{95}$ | 150.5 | 139.4 | 133.8 |
| $L_{mean}$ | 159.1 | 145.6 | 137.3 |

* 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 ($L_{50}$).

JASCO APPLIED SCIENCES

# Underwater Acoustic Monitoring of the Tappan Zee Bridge Test Pile 105P Installation

**Daily Memorandum for 15 October 2013**

*Submitted to:*

[redacted]

*Authors:*

[redacted]


JASCO Applied Sciences

[redacted]


03 January 2014

P001206-001

# 1. Summary

## 1.1. Pile Location and Monitoring Summary

Test Pile PLT-105P is a [redacted] pile driven at the construction site of the New NY Bridge on the west side of the navigation channel on 15 October 2013 (Table 1). One real-time acoustic monitoring system and two autonomous acoustic monitoring systems were deployed by JASCO (Section 4) on behalf of Tappan Zee Constructors, LLC (TZC) (Figure 1 and Table 2). Pile driving occurred 12:21–13:02 Eastern Daylight Time (EDT). Slack tide occurred at 10:07 and full ebb tide occurred at 13:49 EDT.

Table 1. Summary of Test Pile PLT-105P activities, 15 October 2013.

| | |
|---|---|
| Date: | 15 October 2013 |
| ***Pile-Driving Activity*** | |
| Test pile identifier: | PLT-105P |
| Pile diameter: | [redacted] |
| Water depth: | 13 ft |
| Hammer type: | Impact (IHC S-280) |
| Total hammer strikes: | 2295 |
| Total penetration: | 315 ft |
| Net duration of pile driving (hh:mm:ss): | ~ 00:40:00 |
| Maximum single strike energy: | 123 thousand foot-pounds (kip-ft), (167 kJ) |
| Total energy transferred: | ~ 275400 kip-ft (373 MJ) |
| ***Noise Attenuation System (NAS)*** | |
| Two-tier unconfined bubble curtain airflow rate: | 1700–1800 cubic feet per minute (cfm), 65 pounds per square inch (psi) |
| River conditions during pile driving: | Ebb tide, 0.3–1.0 knots current (0.15–0.5 meters per second [m/s]; Table 5, Figure 6) |

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

The pile driving record from the IHC-280 hammer is believed to be corrupt after the depth of [redacted]. Values reported were estimated based on the acoustic detections and the data from the pile driving log that is believed to be correct.

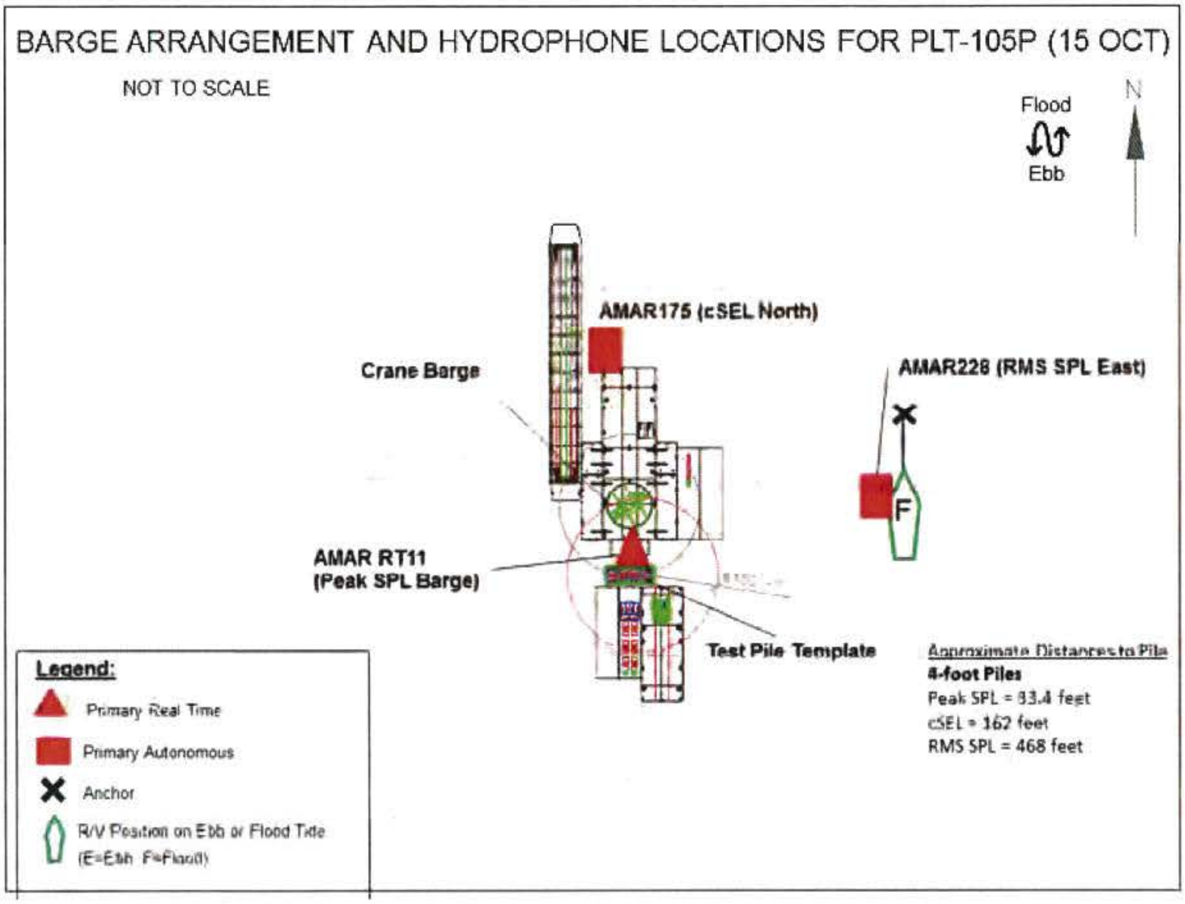



Figure 1. Plan view of pile and barge layout, 15 October 2013, Test Pile PLT-105P.

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 | 33 | 13 | 188 | 197 |
| cSEL North (up current) | AMAR-175 | 163 | 13 | 170 | 180 |
| rms SPL East (cross current) | AMAR-228 | 468 | 12 | 162 | 168 |

* Calculated by multiplying the average SELss by the number of strikes reported by the pile driving contractor. .

## 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 10 ft, and did not exceed NMFS criteria of a diameter of 40 ft for f[redacted] piles. The diameter of the 187 dB re 1 µPa$^2$·s cumulative sound exposure level (cSEL) isopleth was estimated to be 170 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 170 ft for most of the pile driving operation. The river width is approximately 15,000 ft; therefore, a fish-movement corridor of more than one mile, which was continuous for more than 1,500 ft, was maintained throughout pile driving in accordance with New York State Department of Environmental Conservation (NYSDEC) Permit Condition 14.

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

| Criteria | Estimated mean diameter (ft) |
|---|---|
| 206 dB re 1 µPa peak SPL | 10 |
| 187 dB re 1 µPa$^2$·s cSEL* | 170 |
| 150 dB re 1 µPa rms SPL (1 s integration time) | 518 |

*At the end of pile driving

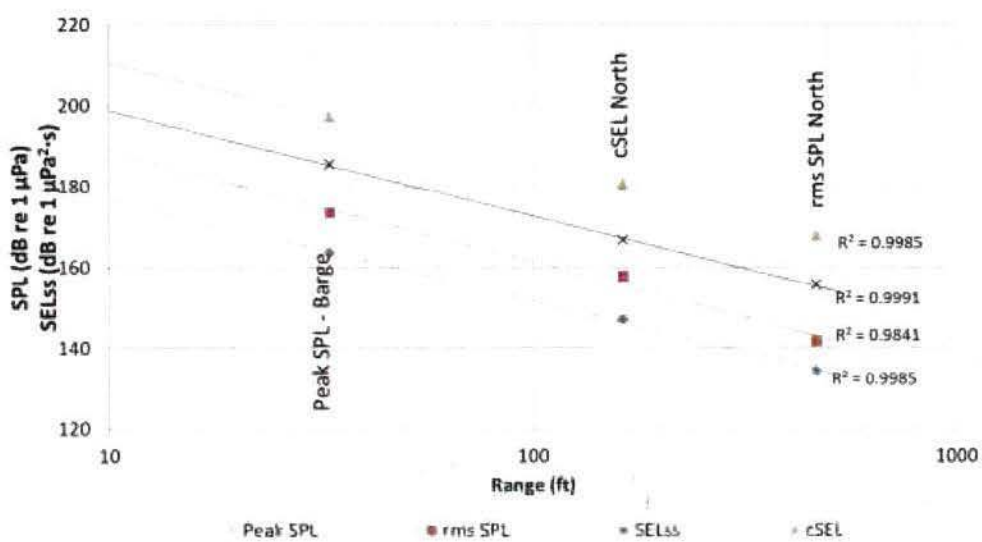



Figure 2. Regression based on mean values of the peak SPL, rms SPL, SELss and cSEL from each recorder from pile driving of Test Pile PLT-105P, 15 October 2013. SELss, peak SPL, and rms SPL are instantaneous values. The cSEL represents the total sound energy measured during the pile driving.

### 1.3. Observations

The hammer energy during pile driving at PLT-105P was nearly constant at 120 ± 5 kip-ft (Figure 4). Similarly the NAS air pressure and airflow were constant at 65 psi and 1750–1800 cfm. Pile driving occurred during the ebb tide, with approximate average currents approximately 0.5–0.7 knots (Figure 6). While the variation in sound levels at the three measurement locations were qualitatively different (Figure 3), there was no observable effect on meeting the NMFS physiological and behavioral thresholds (Figure 2).

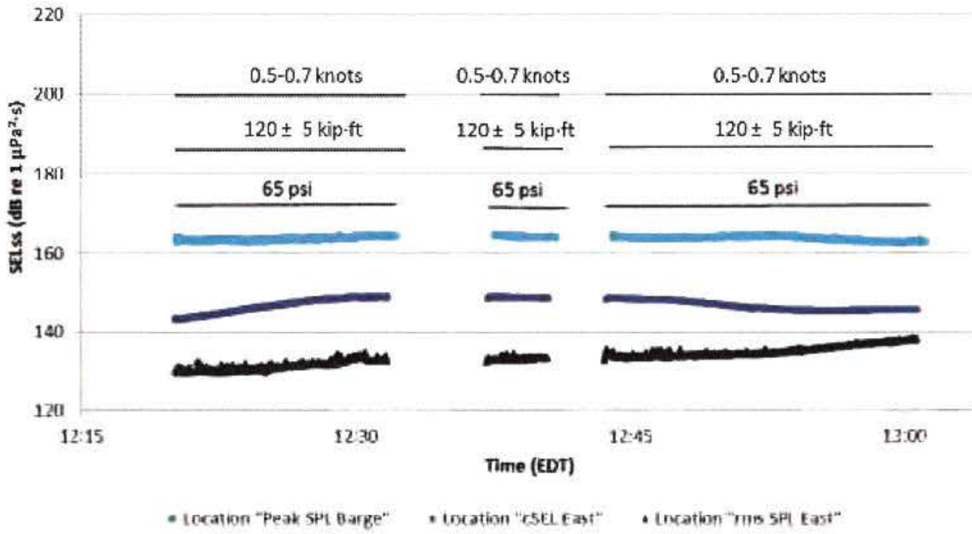



Figure 3. SELss at each location annotated with hammer energy (kip-ft), NAS air pressure (psi), and river current (knots).

## 2. Activity Logs

### 2.1. Log of JASCO and Construction Activities

Table 4 provides activities for 15 October 2013.

Table 4. JASCO and construction activities for Test Pile PLT-105P, 15 October 2013.

| Time (EDT) | Activity |
|---|---|
| 05:55 | Arrive at dock, prep recorders |
| 06:30 | Leave dock for job site; instructed to Stand-by on arrival |
| 10:00 | Start deployment of recorders |
| 10:33 | Complete deployment |
| 11:35 | Begin lifting hammer |
| 12:21 | Start pile driving on PLT-105P |
| 13:02 | Stop pile driving on PLT-105P, standby for PLT-105 |

| | |
|---|---|
| 14:46 | Start pile driving on PLT-105 |
| 15:24 | Stop pile driving on PLT-105; begin retrieval |
| 15:40 | Retrieval complete; en route to dock |
| 16:30 | All work complete. |

## 2.2. Pile Driving Logs

### 2.2.1. NAS

NAS used: Two-tier unconfined bubble curtain

NAS settings: 1750–1800 cfm, 65 psi

### 2.2.2. Impact Hammering Log

The pile driving log from the IHC-280 hammer is believed to be corrupt after a pile depth of [redacted]. This belief is based on the per-strike energy suddenly jumping to 6200 kip-ft and higher. The total penetration reported of [redacted] and the data before the depth of [redacted] are assumed to be correct. The total number of strikes was estimated from the number of detections reported by JASCO's auto-detection algorithm (2295). The total energy was calculated based on 120 kip-ft per strike and 2295 strikes.

Total energy: ~ 275,400 kip-ft (373 MJ)

Total number of strikes: 2295

Maximum per-strike energy: 123 kip-ft (167 kJ)

Net pile driving duration (hh:mm:ss): ~ 00:40:00

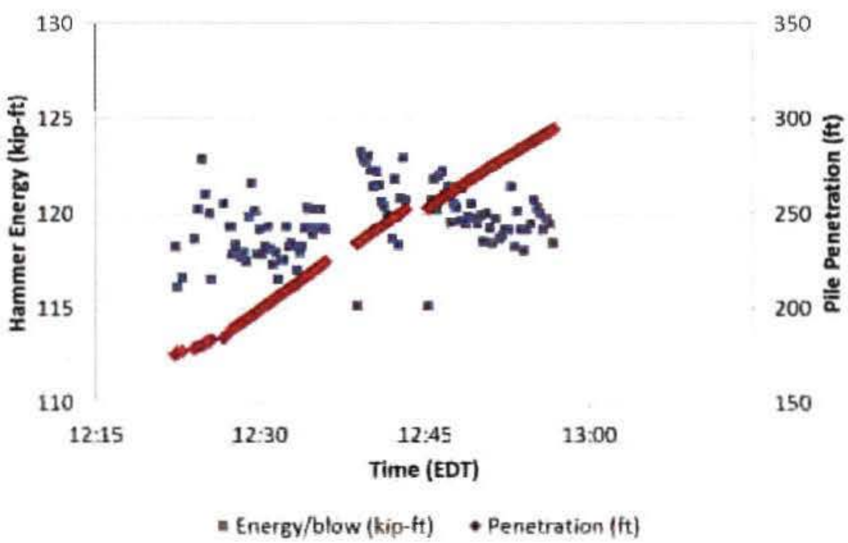



Figure 4. Hammer energy (kip-ft) and pile penetration (ft) during pile driving of PLT-105P, 15 October 2013. The pile driving record from the IHC-280 is believed to be corrupted after the depth of [redacted]. Pile driving finished at a depth of [redacted] at 13:02 EDT.

# 3. Weather and River Conditions

Table 5 provides the predicted currents at the project site on 15 October 2013. Figure 5 provides the speed of sound in water, based on salinity and temperature, measured using the conductivity, temperature, depth (CTD) cast. Figure 6 provides the currents measured at the project site on 15 October using an Active Doppler Current Profiler (ADCP). **Error! Reference source not found.**

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

| | |
|---|---|
| Weather conditions: | Sunny, light winds |
| Full ebb current: | 13:49 (−2.2 knots) |
| Slack current: | 10:07 |
| Full flood current: | N/A |

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

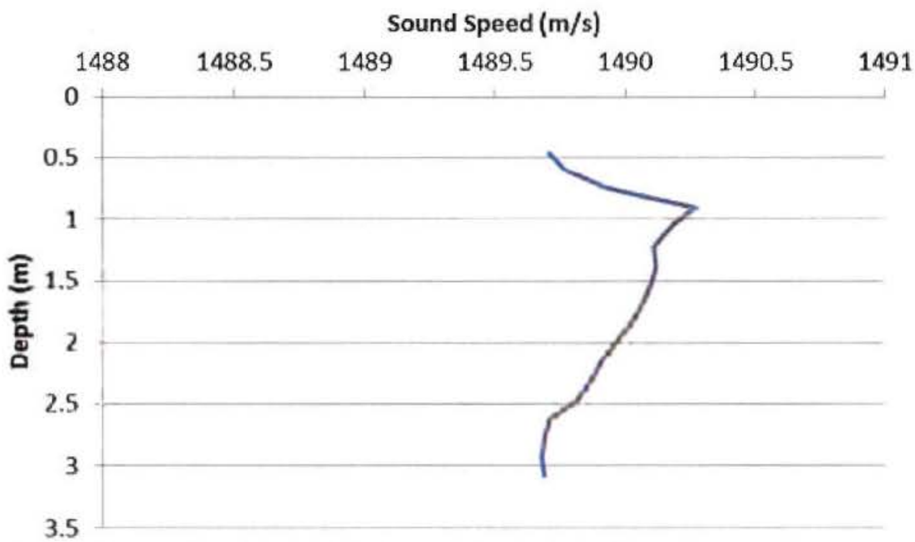



Figure 5. CTD cast performed at 12:24 EDT from the Alpine vessel, located 426.5 ft East of the pile (41.0707 N, 73.9022 W).

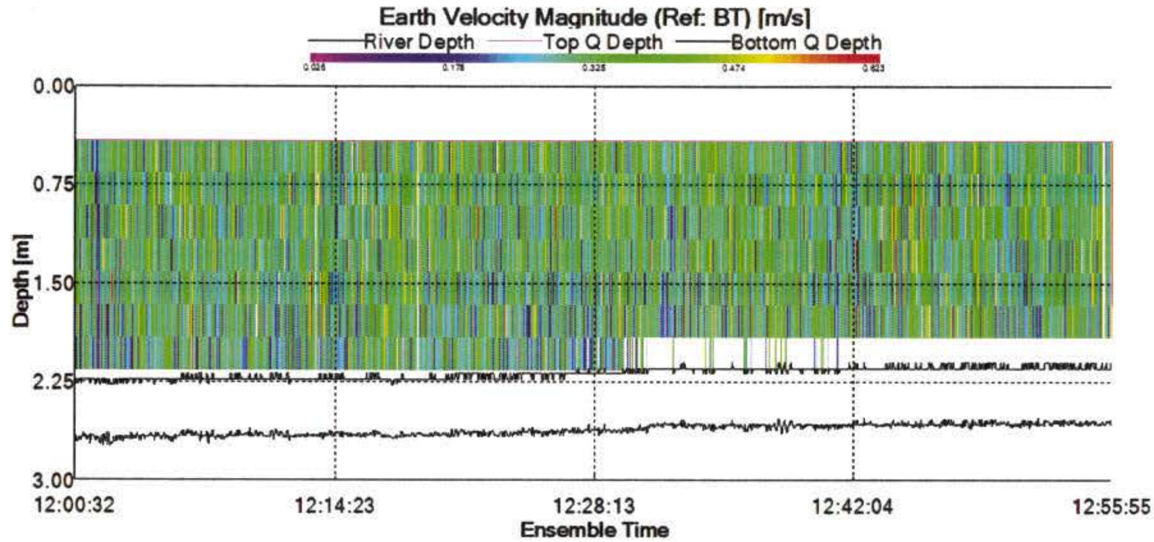



Figure 6. ADCP river current measurements for 15 October 2013 recorded at location rms SPL East (Alpine vessel).

# 4. Monitoring Equipment

## *4.1. Real-time Monitoring Equipment*

Table 6 provides information on the real-time monitoring equipment used on 15 October 2013. Table 7 provides location information on the real-time recorders.

Table 6. Real-time monitoring equipment for Test Pile PLT-105P, 15 October 2013.

| Equipment used | | Units deployed |
|---|---|---|
| ***Acoustic data logger*** | | |
| Model: | AMAR RT (JASCO Applied Sciences) | 1 |
| *SpectroPlotter* version: | 6.0.1 | 1 |
| ***Hydrophone*** | | |
| Model: | M8KC (GTI) | 1 |
| AMAR-RT-11 sensitivity: | −211.1 dB re 1 V/µPa | 1 |
| ***Other*** | | |
| Hydrophone calibrator: | Pistonphone Type 42AC (G.R.A.S. Sound and Vibration) | 1 |
| CTD profiler: | Minos X (AML Oceanographic) | 1 |
| ADCP: | RDI Teledyne Workhorse Sentinel 1200 kHz | 1 |

Table 7. Locations (WGS84) and deployment times (EDT) of the AMAR-RT monitoring stations, 15 October 2013.

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time (EDT) | Water depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| Peak SPL Barge (up current) | AMAR-RT-11 | 41.07126 | 73.90521 | 07:30 | 13 | 33 |

## 4.2. Autonomous Monitoring Equipment

Table 8 provides information about the autonomous monitoring equipment used on 15 October 2013. Table 9 provides the locations of the autonomous recorders.

Table 8. Autonomous monitoring equipment for PLT-105P, 15 October 2013.

| Equipment used | | Units deployed |
|---|---|---|
| ***Acoustic data logger*** | | |
| Model: | AMAR G3 (JASCO Applied Sciences) | 2 |
| *SpectroPlotter* version: | 6.0.1 | 2 |
| ***Hydrophone*** | | |
| Model: | M8E-51-0dB (GTI) | 2 |
| AMAR-228 sensitivity: | −199.54 dB re 1 V/µPa | 1 |
| AMAR-175 sensitivity: | −200.64 dB re 1 V/µPa | 1 |

Table 9. Locations (WGS84) and deployment times (EDT) of the long-range monitoring AMAR stations on 15 October 2013

| Station | Recorder ID | Latitude (°N) | Longitude (°W) | Deployment time (EDT) | Water depth (ft) | Distance to pile (ft) |
|---|---|---|---|---|---|---|
| cSEL North (up current) | AMAR-175 | 41.07158 | -73.9101 | 10:00 | 13 | 163 |
| rms SPL East (cross current) | AMAR-228 | 41.0707 | -73.9022 | 10:20 | 12 | 468 |

# Appendix A. Pile Driving Plots

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

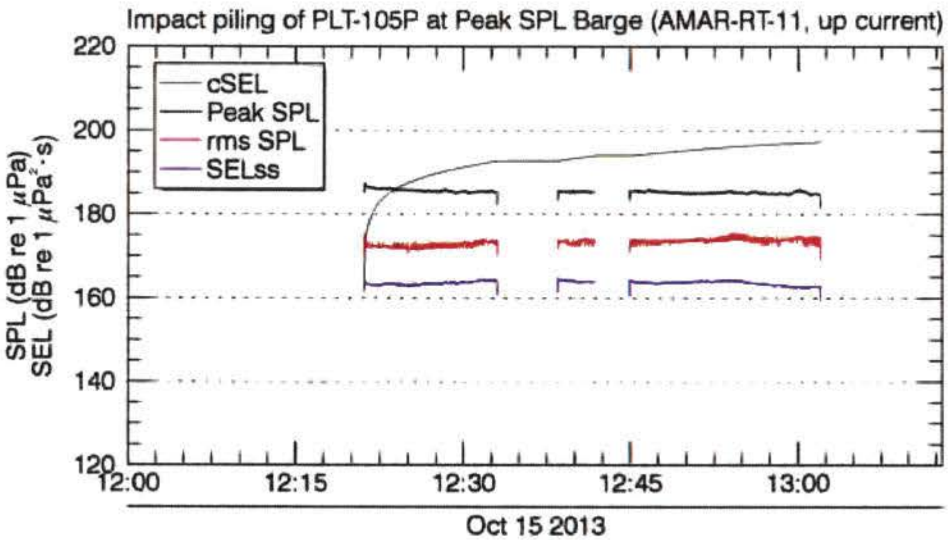



Figure 7. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-105P measured 33 ft from the pile at location Peak SPL Barge using AMAR-RT-11. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

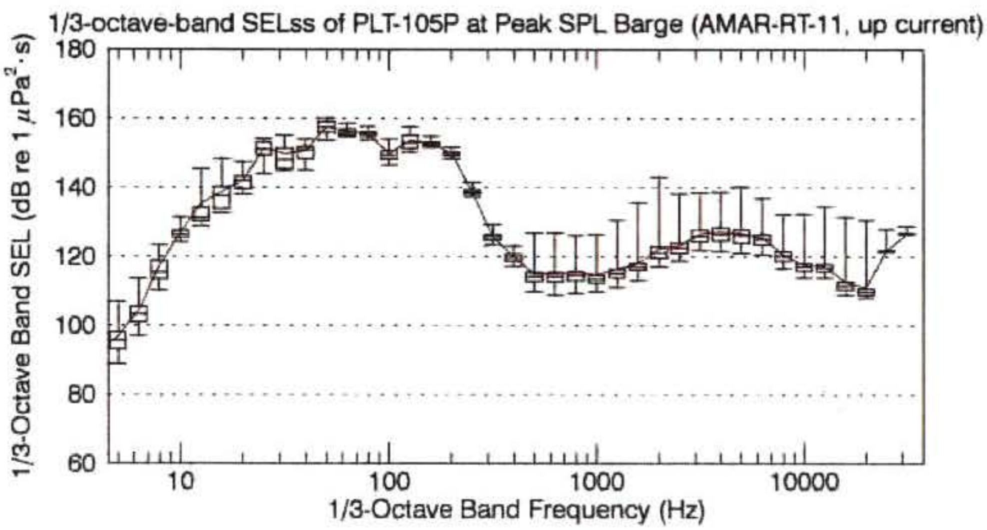



Figure 8. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-105P measured 33 ft from the pile at location Peak SPL Barge using AMAR-RT-11. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 10. Sound levels for the pile driving of Test Pile PLT-105P measured 33 ft from the pile at location Peak SPL Barge using AMAR-RT-11.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 187.5 | 175.7 | 164.6 |
| $L_5$ | 186.1 | 174.6 | 164.2 |
| $L_{25}$ | 185.6 | 174.0 | 164.0 |
| $L_{50}$ | 185.4 | 173.5 | 163.6 |
| $L_{75}$ | 185.1 | 172.8 | 163.2 |
| $L_{95}$ | 184.8 | 171.8 | 162.7 |
| $L_{mean}$ | 185.4 | 173.5 | 163.6 |

* 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

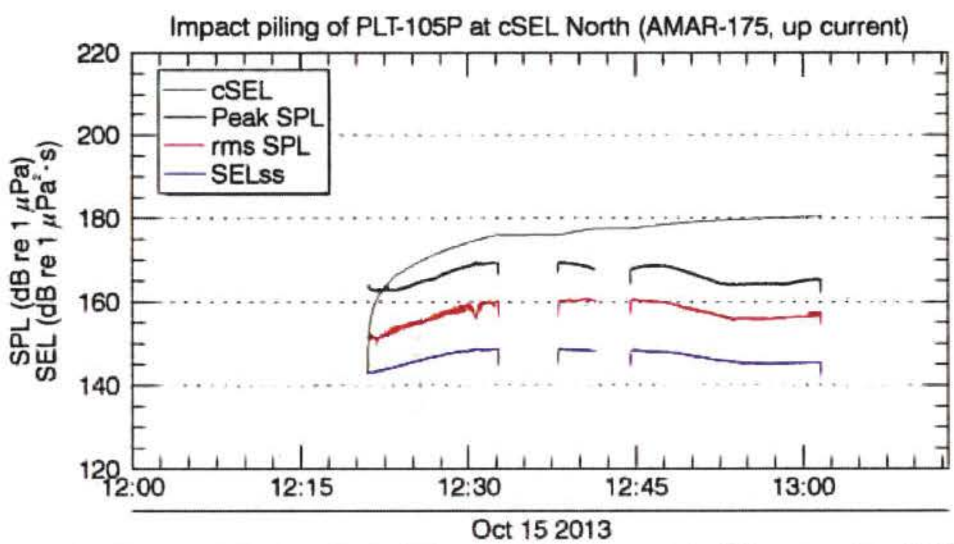



Figure 9. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-105P measured 163 ft from the pile at location cSEL North using AMAR-175. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

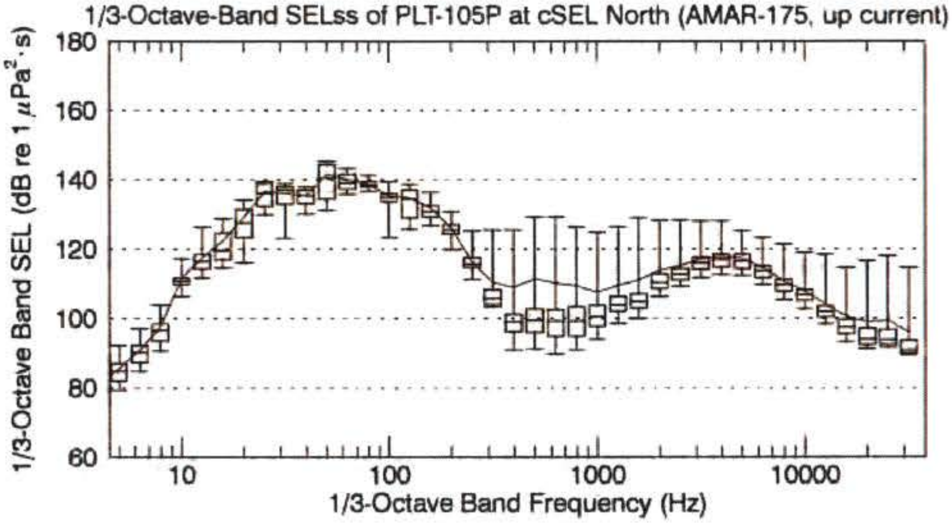



Figure 10. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-105P measured 163 ft from the pile at location cSEL North using AMAR-175. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 11. Sound levels for the pile driving of Test Pile PLT-105P measured 163 ft from the pile at location cSEL North using AMAR-175.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 169.7 | 160.7 | 148.8 |
| $L_5$ | 169.2 | 160.4 | 148.6 |
| $L_{25}$ | 168.3 | 159.7 | 148.1 |
| $L_{50}$ | 165.5 | 157.1 | 146.6 |
| $L_{75}$ | 164.2 | 155.9 | 145.3 |
| $L_{95}$ | 162.9 | 152.2 | 144.0 |
| $L_{mean}$ | 166.6 | 157.8 | 146.9 |

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

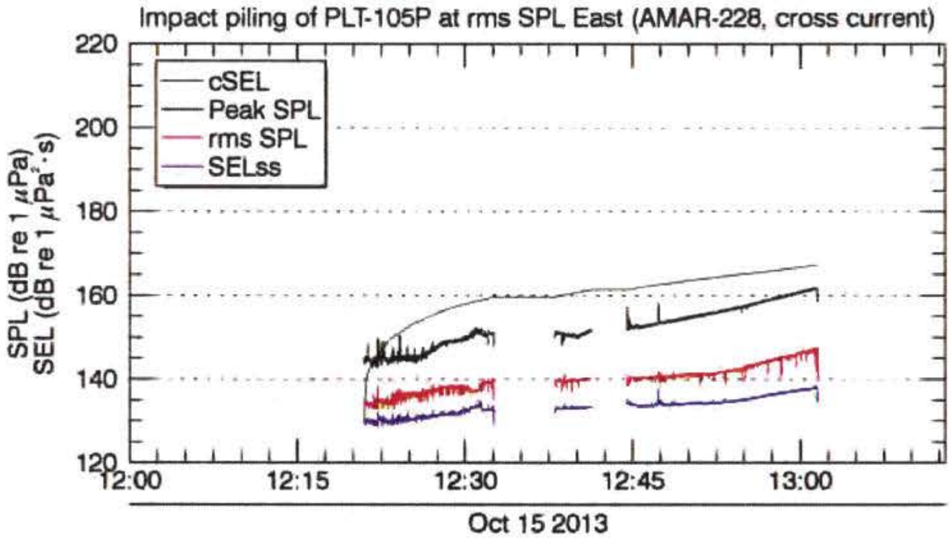



Figure 11. *Impact Pile Driving*: Peak SPL, rms SPL, SELss and cSEL versus time (EDT) for the pile driving of Test Pile PLT-105P measured 468 ft from the pile at location rms SPL East using AMAR-228. For periods during which there is no pile driving the cSEL is necessarily displayed as a constant value over time.

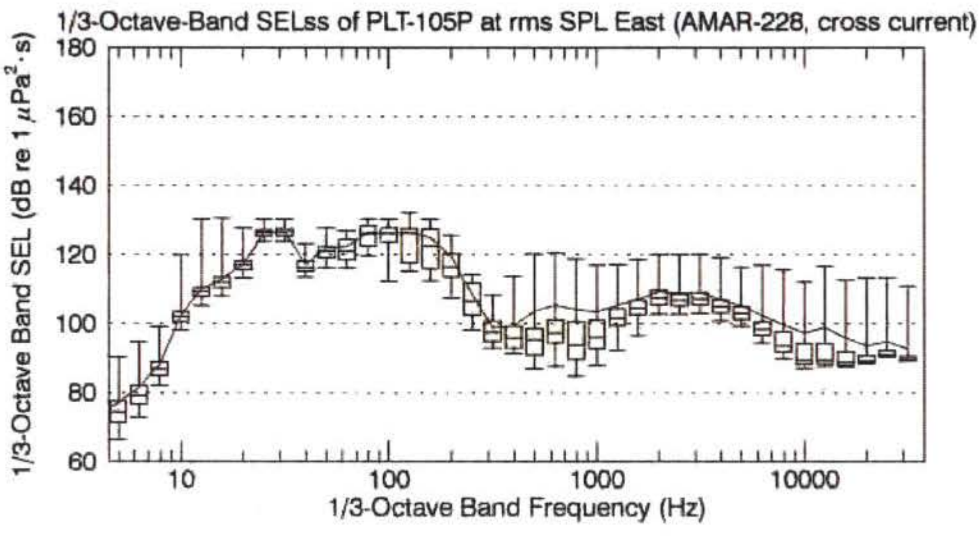


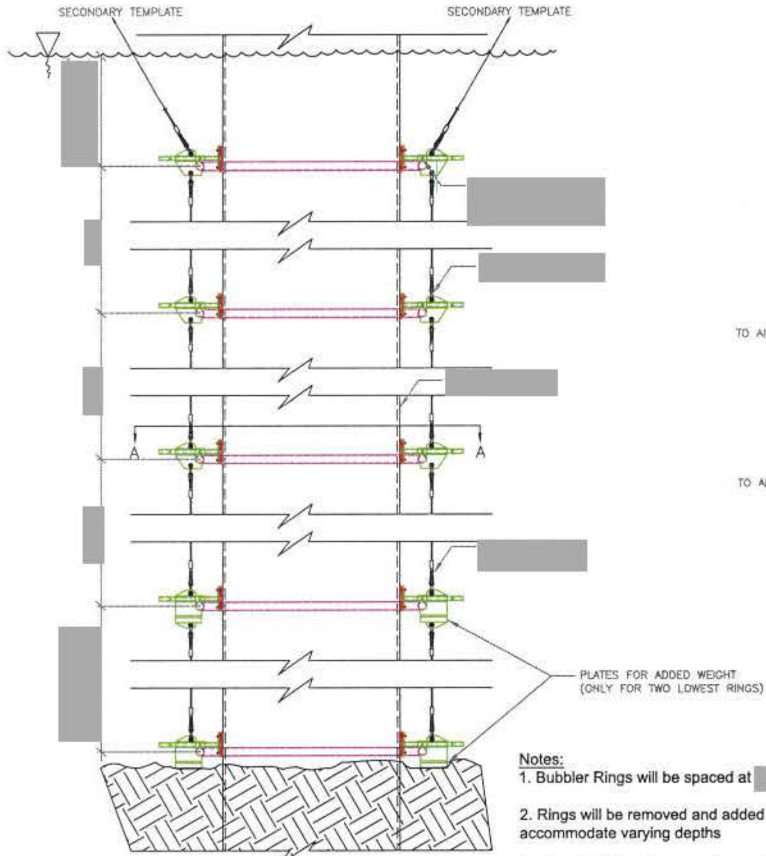

Figure 12. Distribution of 1/3-octave-band SELss for the pile driving of Test Pile PLT-105P measured 468 ft from the pile at location rms SPL East using AMAR-228. Beige bars indicate the first, second, and third quartiles ($L_{25}$, $L_{50}$, and $L_{75}$). Upper error bars indicate the maximum levels ($L_{max}$). Lower error bars indicate the 95% exceedance percentiles ($L_{95}$). The maroon line indicates the arithmetic mean ($L_{mean}$).

Table 12. Sound levels octave for the pile driving of Test Pile PLT-105P measured 468 ft from the pile at location rms SPL East using AMAR-228.

| Sound level statistic* | peak SPL (dB re 1 µPa) | rms SPL (dB re 1 µPa) | SELss (dB re 1 µPa$^2$·s) |
|---|---|---|---|
| $L_{max}$ | 161.8 | 147.8 | 138.3 |
| $L_5$ | 160.9 | 146.2 | 137.4 |
| $L_{25}$ | 156.9 | 142.1 | 134.9 |
| $L_{50}$ | 153.1 | 140.3 | 133.8 |
| $L_{75}$ | 149.8 | 138.1 | 132.4 |
| $L_{95}$ | 144.6 | 134.8 | 129.9 |
| $L_{mean}$ | 155.5 | 141.6 | 134.2 |

* 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 ($L_{50}$).

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

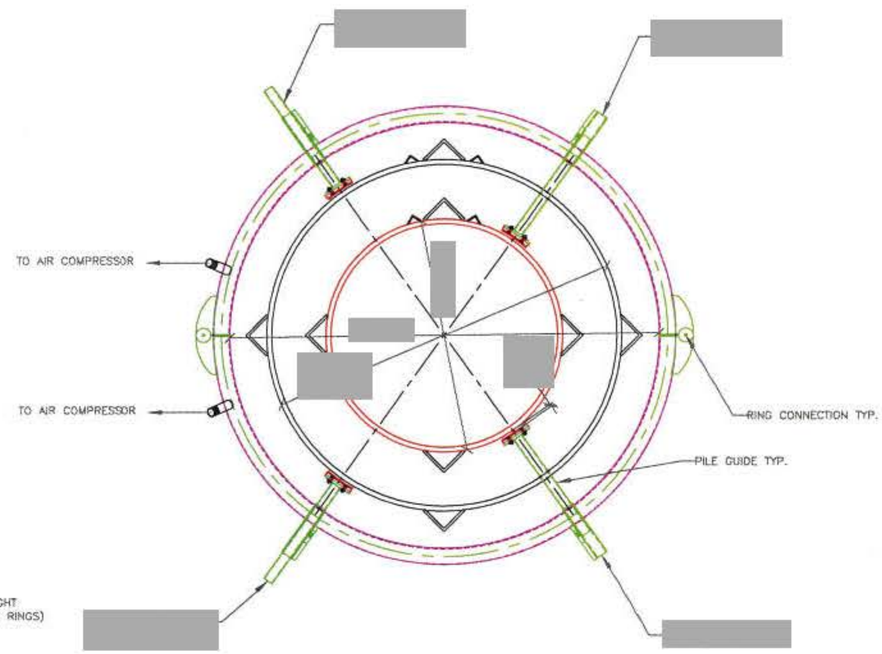



**ELEVATION - BUBBLER RINGS 72" PILE**
SCALE: NTS

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

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

3. These Bubbler Rings can be used on [redacted] diameter piles




A/- **PLAN - BUBBLER RINGS**
SCALE: NTS

| REVISIONS | | | |
|---|---|---|---|
| DATE | DESCRIPTION | BY | SYM. |

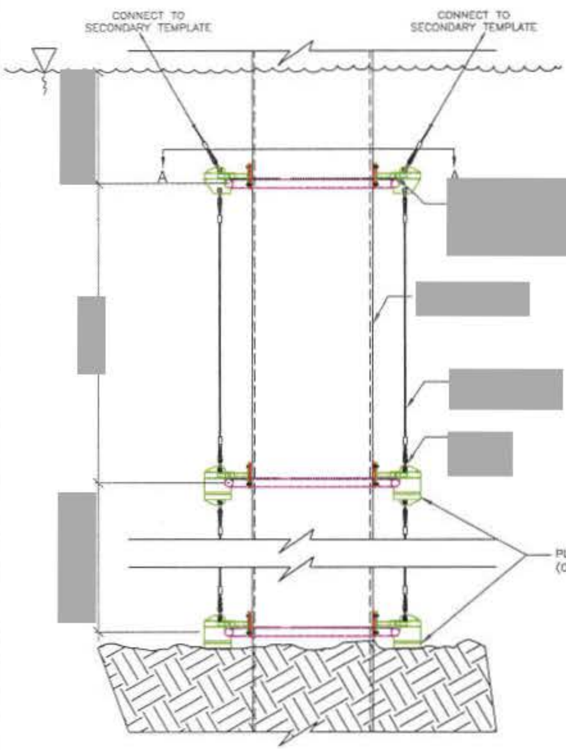
NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

| | |
|---|---|
| TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE — | CONTRACT NUMBER: — |
| LOCATION OF PROJECT: NEW_YORK_STATE — | DATE: 5/20/13 |
| TITLE OF DRAWING: UNCONFINED BUBBLE [redacted] | DRAWING NUMBER: 1UBCR |

DOCUMENT TRACKING CODE: -

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

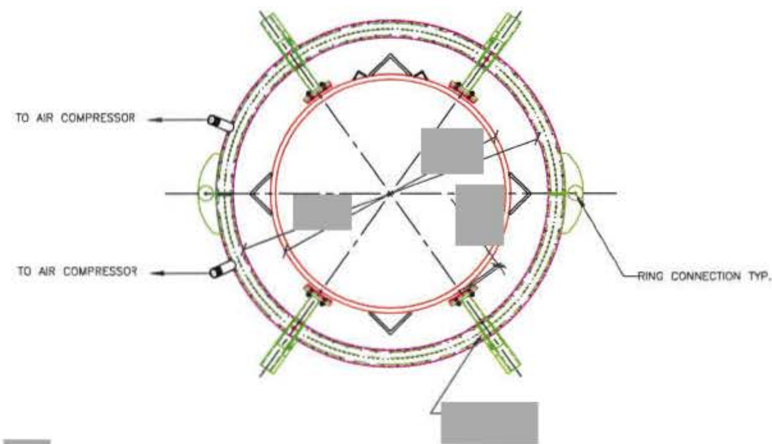



**ELEVATION - BUBBLER RINGS 48" PILES**
SCALE: NTS

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

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

3. These Bubbler Rings can be used on [redacted] piles only




**A PLAN - BUBBLER RINGS**
SCALE: NTS

| REVISIONS | | | |
|---|---|---|---|
| DATE | DESCRIPTION | BY | SYM |
| | | | |

NEW YORK STATE THRUWAY AUTHORITY

TAPPAN ZEE CONSTRUCTORS, LLC

| | |
|---|---|
| TITLE OF PROJECT: TAPPAN_ZEE_BRIDGE | CONTRACT NUMBER: – |
| LOCATION OF PROJECT: NEW_YORK_STATE | DATE: 5/19/13 |
| TITLE OF DRAWING: UNCONFINED_BUBBLE [redacted] | DRAWING NUMBER: 2UBCR |

DOCUMENT TRACKING CODE:

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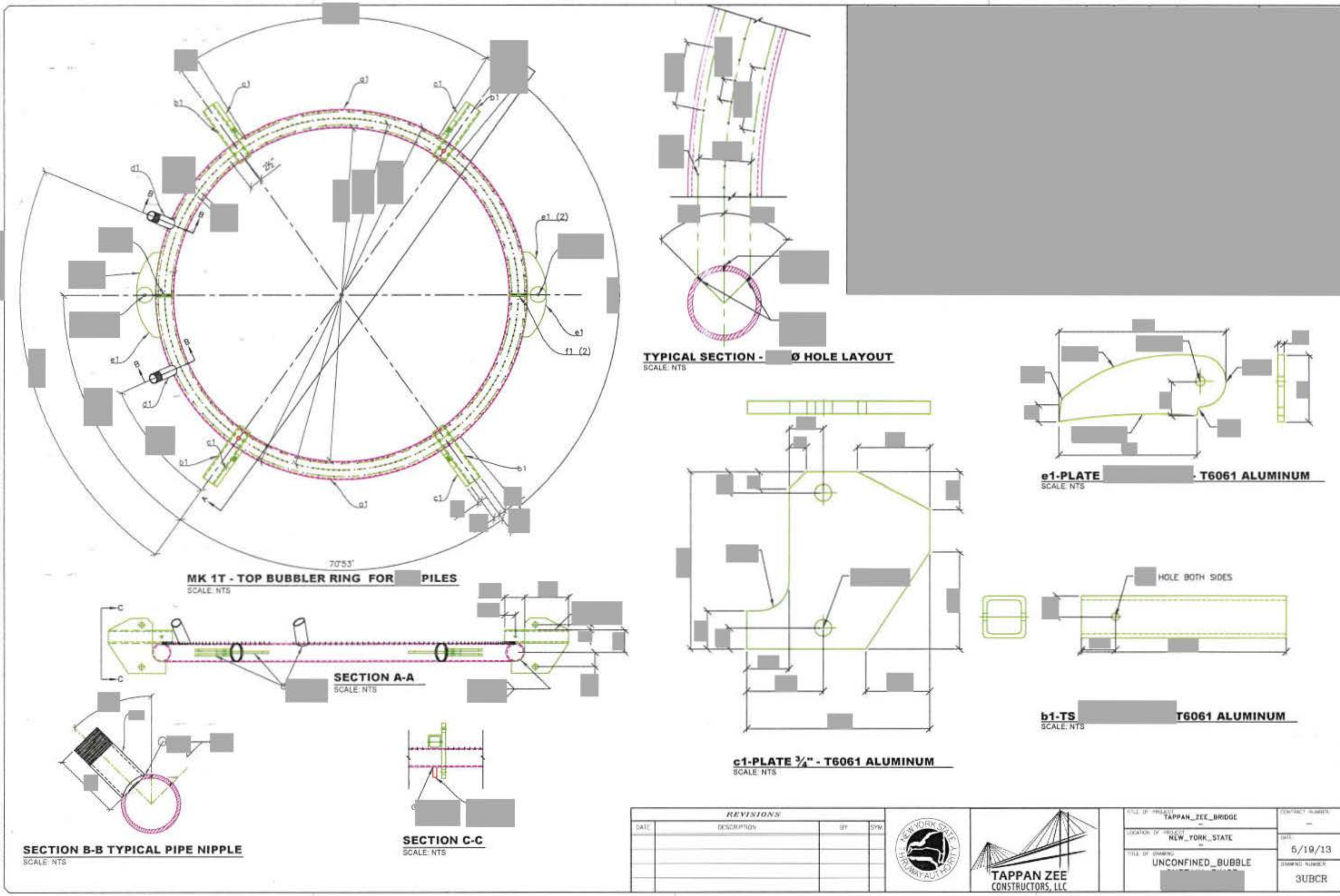
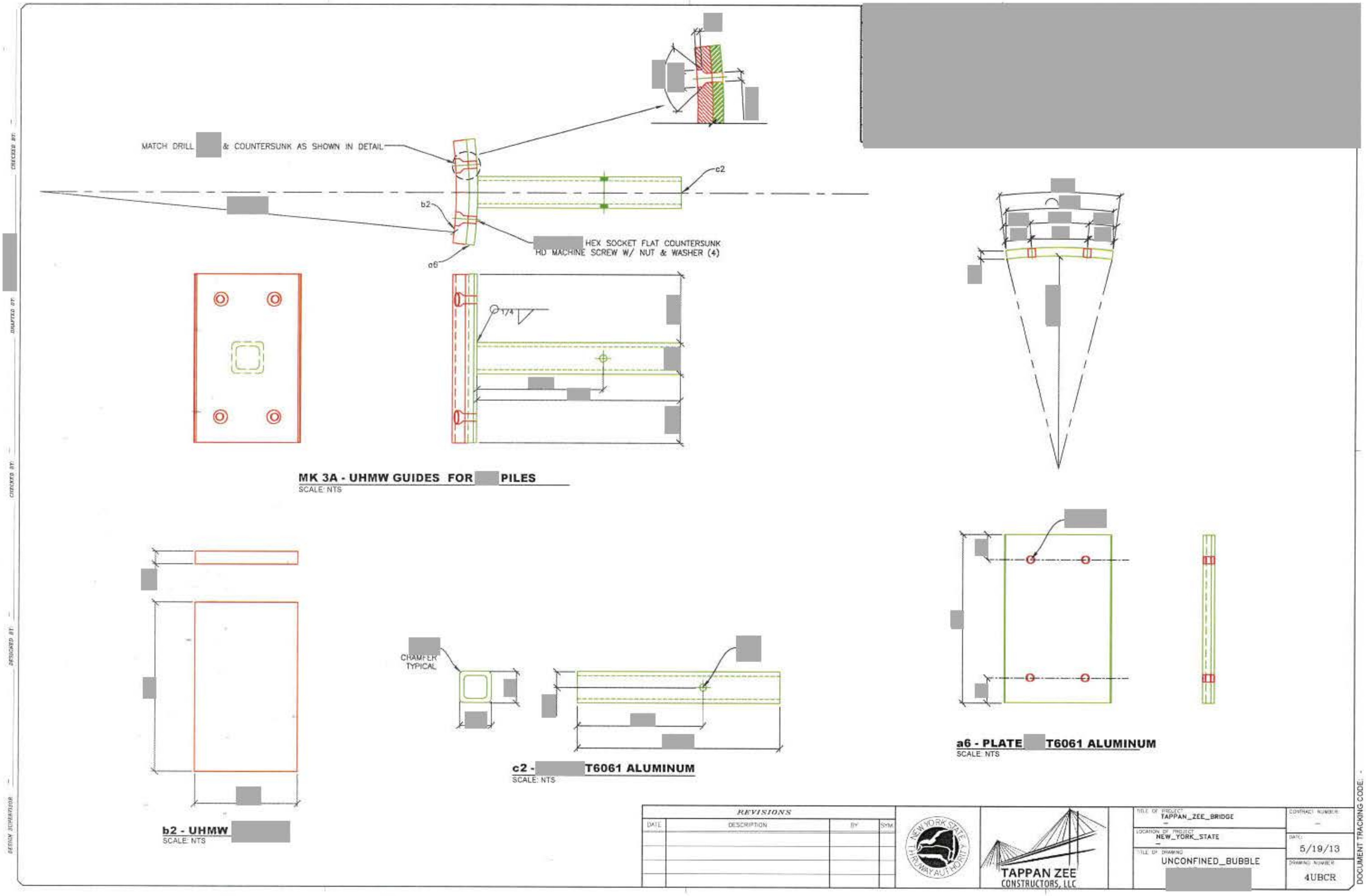


MK 1T - TOP BUBBLER RING FOR [redacted] PILES
SCALE: NTS
70°53'
a1
b1
c1
d1
e1
e1 (2)
f1 (2)
TYPICAL SECTION - [redacted] Ø HOLE LAYOUT
SCALE: NTS
e1-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS
[redacted] HOLE BOTH SIDES
b1-TS [redacted] T6061 ALUMINUM
SCALE: NTS
c1-PLATE ¾" - T6061 ALUMINUM
SCALE: 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 [redacted]
CONTRACT NUMBER: —
DATE: 5/19/13
DRAWING NUMBER: 3UBCR
DOCUMENT TRACKING CODE:
DESIGN SUPERVISOR
DESIGNED BY
CHECKED BY
DRAFTED BY
CHECKED BY


CHECKED BY:
DRAFTED BY:
CHECKED BY:
DESIGNED BY:
DESIGN SUPERVISOR
[redacted]
MATCH DRILL [redacted] & COUNTERSUNK AS SHOWN IN DETAIL
c2
b2
a6
[redacted] HEX SOCKET FLAT COUNTERSUNK HD MACHINE SCREW W/ NUT & WASHER (4)
1/4
MK 3A - UHMW GUIDES FOR [redacted] PILES
SCALE: NTS
CHAMFER TYPICAL
c2 - [redacted] T6061 ALUMINUM
SCALE: NTS
a6 - PLATE [redacted] T6061 ALUMINUM
SCALE: NTS
b2 - UHMW [redacted]
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
[redacted]
CONTRACT NUMBER
DATE: 5/19/13
DRAWING NUMBER 4UBCR
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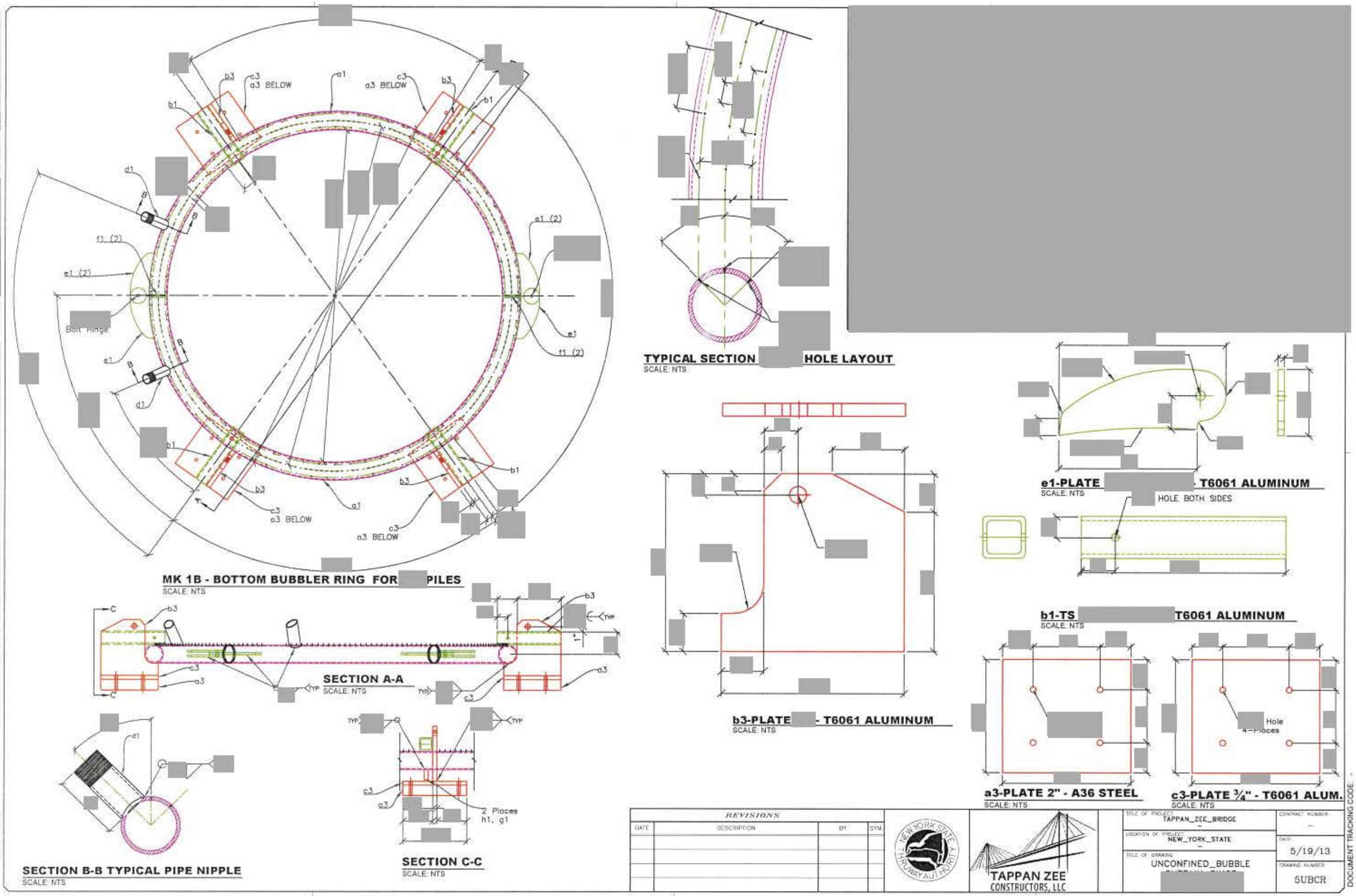

MK 1B - BOTTOM BUBBLER RING FOR [redacted] PILES
SCALE: NTS
TYPICAL SECTION [redacted] HOLE LAYOUT
SCALE: NTS
e1-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS
HOLE BOTH SIDES
b1-TS [redacted] T6061 ALUMINUM
SCALE: NTS
b3-PLATE [redacted] - T6061 ALUMINUM
SCALE: NTS
SECTION A-A
SCALE: NTS
a3-PLATE 2" - A36 STEEL
SCALE: NTS
c3-PLATE ¾" - T6061 ALUM.
SCALE: NTS
Hole
4-Places
SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS
SECTION C-C
SCALE: NTS
2 Places
h1, g1
a3 BELOW
Bolt Hinge
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 [redacted]
CONTRACT NUMBER: —
DATE: 5/19/13
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DESIGNED BY:
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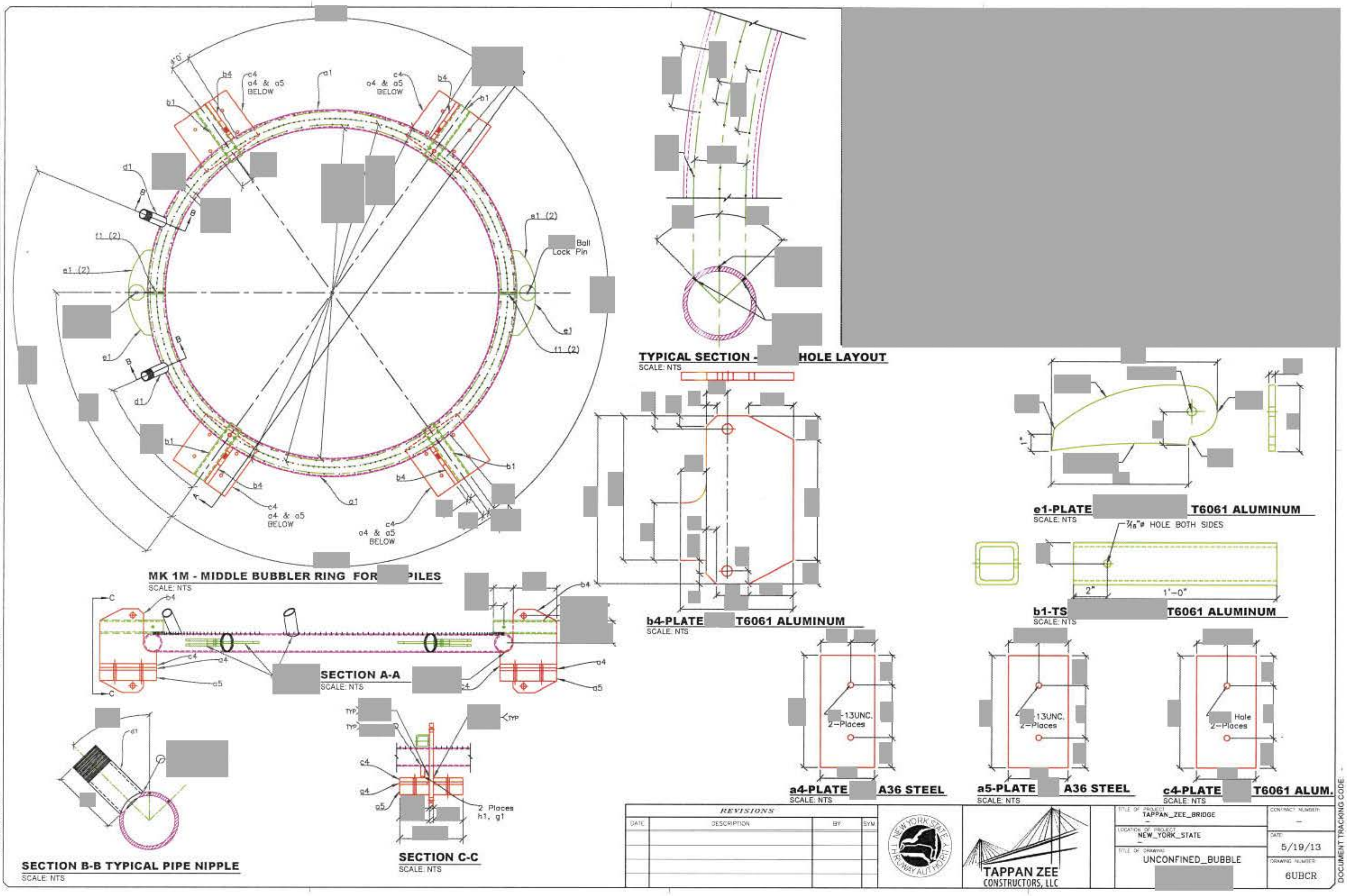
CHECKED BY:


MK 1M - MIDDLE BUBBLER RING FOR [redacted] PILES
SCALE: NTS
b4
c4
a4 & a5
BELOW
a1
b1
d1
f1 (2)
e1 (2)
[redacted] Ball
Lock Pin
e1
B
TYPICAL SECTION - [redacted] HOLE LAYOUT
SCALE: NTS
b4-PLATE [redacted] T6061 ALUMINUM
SCALE: NTS
e1-PLATE [redacted] T6061 ALUMINUM
SCALE: NTS
7/8"ø HOLE BOTH SIDES
2"
1'-0"
b1-TS [redacted] T6061 ALUMINUM
SCALE: NTS
SECTION A-A
SCALE: NTS
a5
a4
c4
SECTION B-B TYPICAL PIPE NIPPLE
SCALE: NTS
SECTION C-C
SCALE: NTS
TYP
2 Places
h1, g1
g5
[redacted]-13UNC.
2-Places
[redacted] Hole
2-Places
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
[redacted]
CONTRACT NUMBER
—
DATE
5/19/13
DRAWING NUMBER
6UBCR
DOCUMENT TRACKING CODE:
DESIGN SUPERVISOR:
DESIGNED BY:
CHECKED BY:
DRAFTED BY:
CHECKED BY:

# 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

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

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