# ELLIOTT BAY SEAWALL PROJECT SEASON 1 (2014) ACOUSTIC MONITORING REPORT (NWS-2011-778-WRD and NWR-2013-10650)

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## 1.0 EXECUTIVE SUMMARY

This technical report presents the results of airborne and underwater sound level measurements conducted between February 12 and 24, 2014 during impact pile driving of 11 concrete piles and vibratory driving of 12 steel sheet piles during Season 1 (2013/2014 in-water work window) of the Elliott Bay Seawall Project ("Project").

Impact driven concrete piles had broadband underwater peak values between 144 and 202 decibels (dB) re: 1 micropascal (µPa) and 90% root mean square (RMS) values between 134 and 179 dB re: 1 µPa. Vibratory driven steel sheet piles had broadband underwater peak values between 140 and 193 and RMS values between 130 and 168 dB re: 1 µPa.

The average distance required for underwater sound levels to reach the 160 dB isopleth was 341 meters for impact driven concrete piles installed in Zone 1, located south of Colman Dock and 35 meters in Zone 4, located near Waterfront Park. Figure 3.1 presents the locations of Zone 1 and Zone 4 graphically. The average distance required for the RMS sound levels from vibratory sheet pile installation to reach the 120 dB isopleth was 11,188 meters in Zone 1 and 9,321 meters in Zone 4. The average distance to reach background sound level was 215 meters for impact concrete piles and 15 meters for vibratory steel sheets in Zone 1, and 1,610 meters for impact piles and 932 meters and vibratory sheets in Zone 4.

## 2.0 INTRODUCTION

This technical report presents the results of airborne and underwater sound levels measured during vibratory and impact pile driving activities associated with Season 1 (2013/2014 in-water work window) of the Elliott Bay Seawall Project ("Project").

Per the National Marine Fisheries Service (NMFS) Marine Mammal Protection Act Letter of Authorization (LOA) and Endangered Species Act (ESA) Incidental Take Statement, sound level monitoring is required for the first five steel piles and the first five concrete piles driven at the start of each construction season. This acoustic monitoring technical report fulfills the requirements of the LOA and ESA Incidental Take Statement.

Installation of steel and concrete piles took place in two different construction zones during Season 1 (see Section 3.0 of this technical report). Airborne and underwater sound levels were measured at both of these locations between February 12 and 24, 2014. Marine mammal monitoring began on February 11, 2014. The start of acoustic monitoring did not coincide with the beginning of marine mammal monitoring because activities on February 11 were limited to installation of the sheet pile guide, which was considered falsework and did not require acoustic monitoring. During Season 1, sound levels from 12 steel sheet piles (vibratory installation) and 11 concrete piles (impact installation) were measured. While the LOA only requires monitoring of the first five steel piles and first five concrete piles per construction season, site conditions and measured underwater sound levels in excess of the limits established in the LOA warranted monitoring of additional steel piles to verify the effectiveness of mitigation measures implemented to reduce underwater pile driving sound levels.

## 3.0 PROJECT AREA

The construction area is located on Alaskan Way between Washington Street and Virginia Street in Seattle, Washington.

During Season 1, construction pile driving activities took place in two separate locations as shown in Figure 3.1. The southern location was in Zone 1, which is located south of Colman Dock and the northern location was in Zone 4, which is located near Waterfront Park. The Figure below illustrates the project location and the locations of Zones 1 and 4.

**Figure 3.1** Season 1 Construction Zones


*Source: The Greenbusch Group, Google Earth Pro, Anchor QEA*

## 4.0 NOMENCLATURE

The auditory response to sound is a complex process that occurs over a wide range of frequencies and intensities. Decibel levels, or “dB,” are a form of shorthand that compresses this broad range of levels with a convenient numerical scale. The dB scale is logarithmic. For example, using the dB scale, a doubling or halving of energy causes the sound level to change by 3 dB, it does not double or half the perceived loudness as might be expected.

Decibels are defined as the squared ratio of the sound pressure level (SPL) with a reference sound pressure. The reference pressure for airborne sound is 20 micropascals (μPa) and for underwater sound the reference pressure is 1 μPa. The use of 20 μPa in air is convenient because 1 dB re: 20 μPa correlates to the human threshold for hearing. It is important to note that because of these different reference pressures airborne and underwater sound levels cannot be directly compared.

The following descriptors are referenced in this Report:

- **Ambient Sound Level**

  The ambient sound level is the sound pressure level that describes the sound environment at a specified location during a specified time period and is also referred to as "background sound levels". The measured sound levels include contributions from all sound sources, both local and distance, excluding specific sound sources of interest or under investigation. Average background RMS sound levels measured during Season 1 were 163 dB in Zone 1 and 135 dB in Zone 4.

- **Peak**

  The peak sound pressure level is the instantaneous absolute maximum pressure observed during a measured event. Peak pressure can be presented as a pressure or dB referenced to a standard pressure (20 μPa for airborne and 1 μPa for underwater). Peak sound pressure is commonly used during hydroacoustic monitoring to assess the potential injuries to fish.

- **Root Mean Square (RMS)**

  The RMS level is the square root of the average squared-pressure over a given time period. In hydroacoustics, the RMS level has been used by the National Marine Fisheries Service (NMFS) in criteria for assessing impacts to marine mammals.

## 5.0 REGULATORY CRITERIA

The LOA and ESA Biological Opinion identify maximum permissible underwater sound level limits for in-water pile driving activities. These sound level limits are presented in Table 5.1.

**Table 5.1** Underwater Sound Level Limits, dB re: 1 μPa

| Pile Type and Approximate Size | Method | Relative Water Depth of Piles | Average Sound Pressure Measured in dB | |
|---|---|---|---|---|
| | | | Peak | RMS |
| 16.5 inch diameter precast concrete octagonal pile | Impact | ~15 meters | 188 | 176 |
| Steel sheet pile pair, 48 inches long per pair | Vibratory (Installation and Removal) | ~15 meters | 182 | 165 |
| Steel sheet pile pair, 48 inches long per pair | Impact (Installation Proofing) | ~15 meters | 205 | 190 |

*Source: MMPA Letter of Authorization Rule (California Department of Transportation, Washington State Department of Transportation)*

These sound level limits are established 10 meters from the pile. The peak sound pressure level is the highest absolute value of the instantaneous pressure measured by the hydrophones, at a distance of 10 meters. The RMS sound pressure is the root-mean-square pressure that contains 90% of the energy within the pile strike.

# 6.0 METHODOLOGY

## 6.1 Equipment

Equipment used for airborne and underwater noise measurements is identified in Table 6.1.

**Table 6.1** Airborne and Underwater Sound Measurement Equipment

| Make and Model | Quantity | Description | Serial Number |
|---|---|---|---|
| | | *Airborne* | |
| Bruel and Kjaer 2250 | 1 | Sound Level Analyzer | 2679351 |
| Bruel and Kjaer 4189 | 1 | Microphone | 2550228 |
| Bruel and Kjaer ZC 0032 | 1 | Preamplifier | 9437 |
| Bruel and Kjaer Type 4231 | 1 | Acoustic Calibrator | 0013 |
| | | *Underwater* | |
| Reson TC-4013 | 4 | Hydrophone | 2513054 |
| | | | 712213 |
| | | | 2513074 |
| | | | 1812260 |
| Bruel and Kjaer Type 2647 A | 3 | Charge Converter (1mV/pC) | 2638259 |
| | | | 2638260 |
| | | | 2582112 |
| Bruel and Kjaer Type 2647 B | 1 | Charge Converter (10mV/pC) | 2293151 |
| G.R.A.S. Pistonphone | 1 | Calibrator | 160184 |
| National Instruments NI USB-4431 | 1 | 4 Channel DAQ | 14F31A5 |
| Getac S400 | 1 | Laptop Computer | RBB39S0072 |

*Source: The Greenbusch Group*

All equipment was factory calibrated within 1 year of the measurement date. Field calibration measurements were performed before each day of monitoring and verified at the end of the day. Calibration tones were also recorded from each hydrophone before every day of monitoring. Hydrophones were calibrated using the G.R.A.S. pistonphone.

Hydrophones were attached to charge converters. These charge converters were then attached to a laptop-based 4-channel data acquisition system. The laptop recorded the time waveforms from each pile driving event for subsequent signal analysis. This equipment setup allowed for real-time approximations of peak sound levels while the measurements were being performed.

Photos illustrating the airborne and hydroacoustic measurement equipment are provided below.

**Figure 6.1** Airborne Measurement Equipment

*Source: The Greenbusch Group, Inc.*

**Figure 6.2** Hydroacoustic Equipment

*Source: The Greenbusch Group, Inc.*

## 6.2 Measurement Locations

Airborne sound levels measurements were conducted at a stationary location during all measured pile driving events. The distance from the measurement location to the pile was recorded to allow the data to be normalized to a standardized required reference distance of 50 feet (15 meters).

Hydroacoustic monitoring was performed using up to four hydrophones at various depths and distances from the piles. The number of hydrophones used and their locations varied depending upon the depth of the water, pile location, and safety concerns.

The airborne and hydroacoustic measurement locations for Zones 1 and 4 are discussed in the Report Sections below.

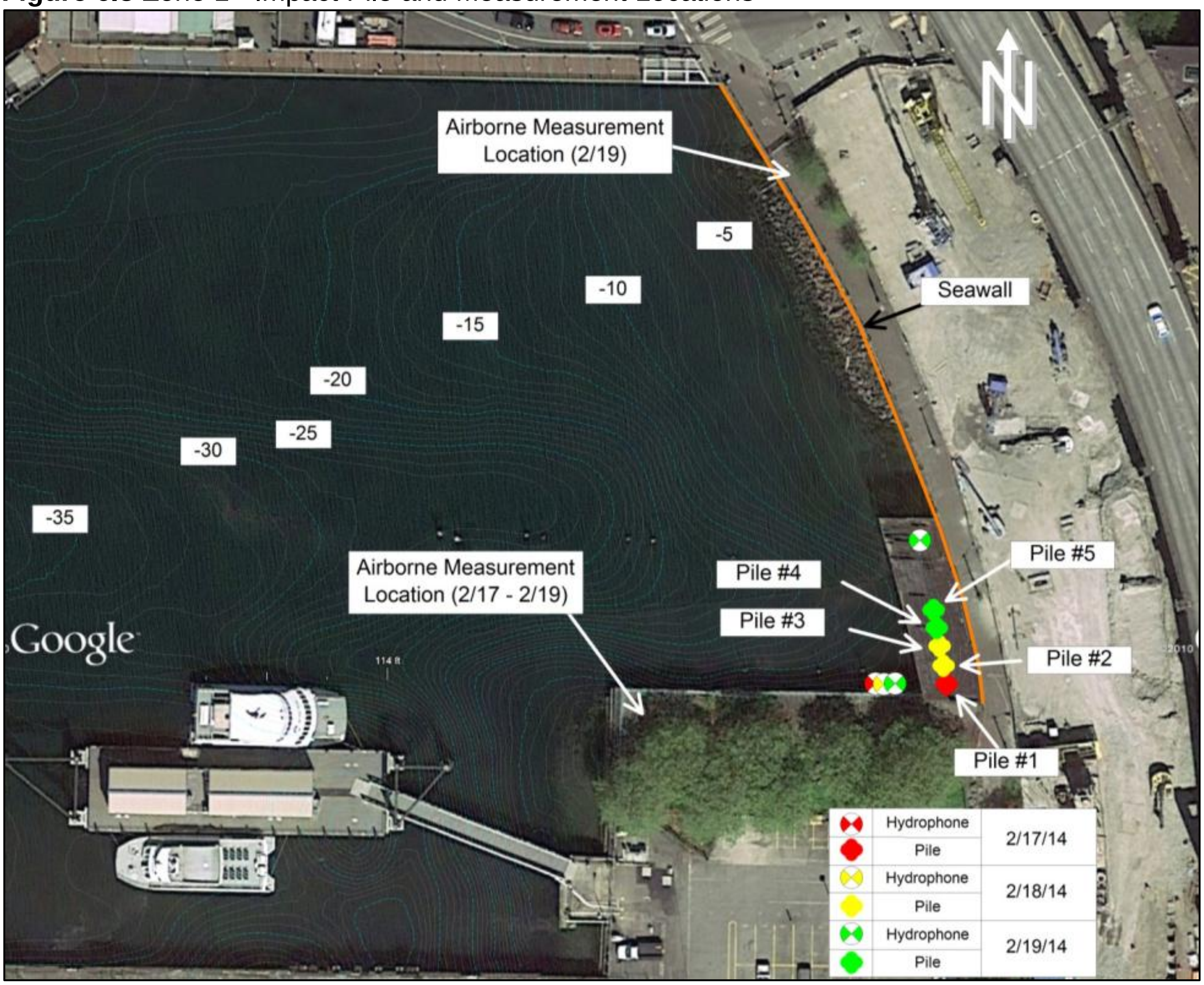
### *6.2.1 Zone 1*

Measurements of impact-driven concrete piles were performed in Zone 1 between February 17 and February 19, 2014. Vibratory sheet pile monitoring was conducted on February 24, 2014.

#### 6.2.1.1 Impact-Driven Concrete Piles

Airborne and underwater measurements of sound generated by impact-driven concrete piles in Zone 1 were conducted between February 17 and February 19, 2014. One hydrophone was deployed approximately 33 feet (10 meters) from the piles at a depth of 3 feet (1 meter) below the surface. The hydrophone was relocated for each pile to maintain a distance of 33 feet (10 meters) from the pile. Figure 6.3 illustrates the locations of the piles, airborne sound level meter, and hydrophone during impact pile driving in Zone 1.

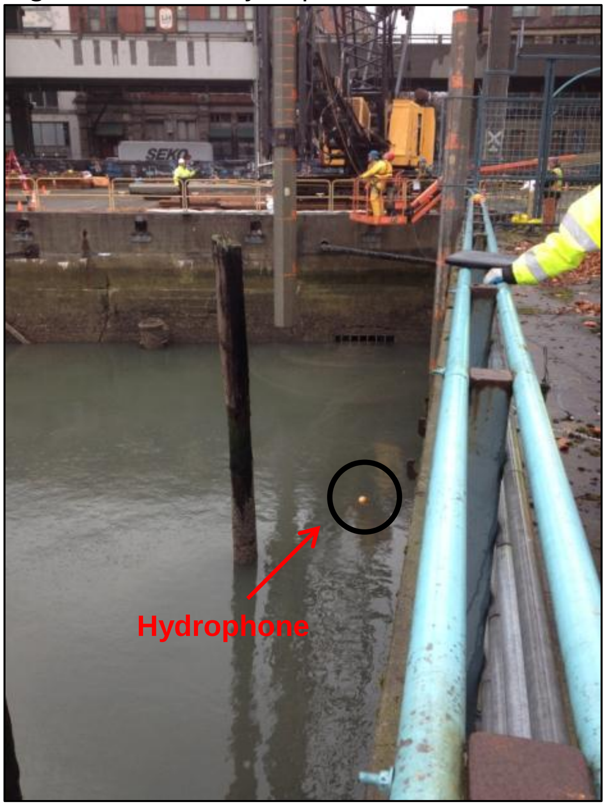
**Figure 6.3** Zone 1 - Impact Pile and Measurement Locations




*Source: The Greenbusch Group Inc.*

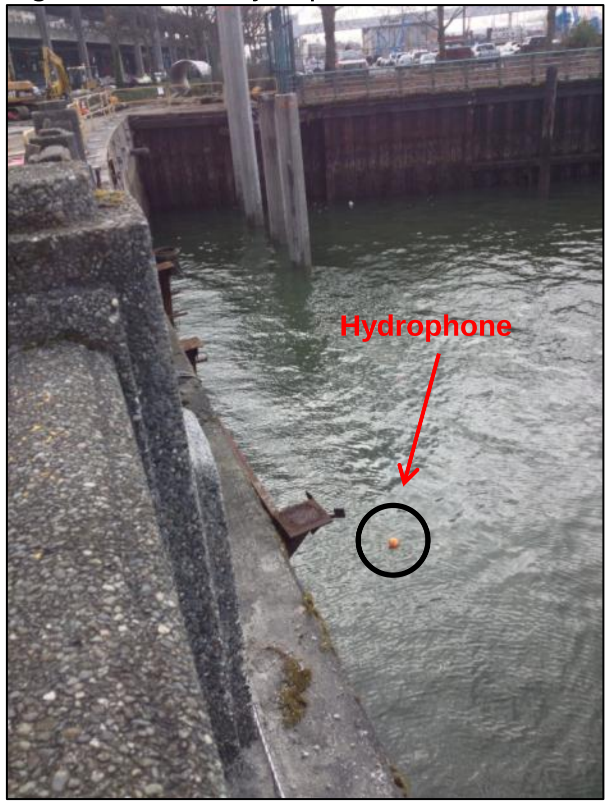
The hydrophone was deployed to the west and southwest of the first four concrete piles. However, due to safety concerns the hydrophone was relocated north of Pile 5 on February 19, 2014. A direct line of acoustic transmission was maintained between the hydrophone and the pile being driven. Photos of the western hydrophone deployment location and the north hydrophone location are shown below.

**Figure 6.4** West Hydrophone Location




*Source: The Greenbusch Group, Inc.*

**Figure 6.5** North Hydrophone Location




*Source: The Greenbusch Group, Inc.*

Table 6.2 presents the depth of the hydrophone, water depth, and distance between the hydrophone and the pile.

**Table 6.2** Zone 1 Hydrophone Location Information for Impact-Driven Concrete Piles

| Pile | Water Depth | Hydrophone Depth | Distance to Pile |
|---|---|---|---|
| Pile #1 | ~8 feet | ~3 feet | ~33 feet |
| Pile #2 | ~8 feet | ~3 feet | ~33 feet |
| Pile #3 | ~8 feet | ~3 feet | ~33 feet |
| Pile #4 | ~8 feet | ~3 feet | ~33 feet |
| Pile #5 | ~8 feet | ~3 feet | ~33 feet |

*Source: The Greenbusch Group, Inc.*

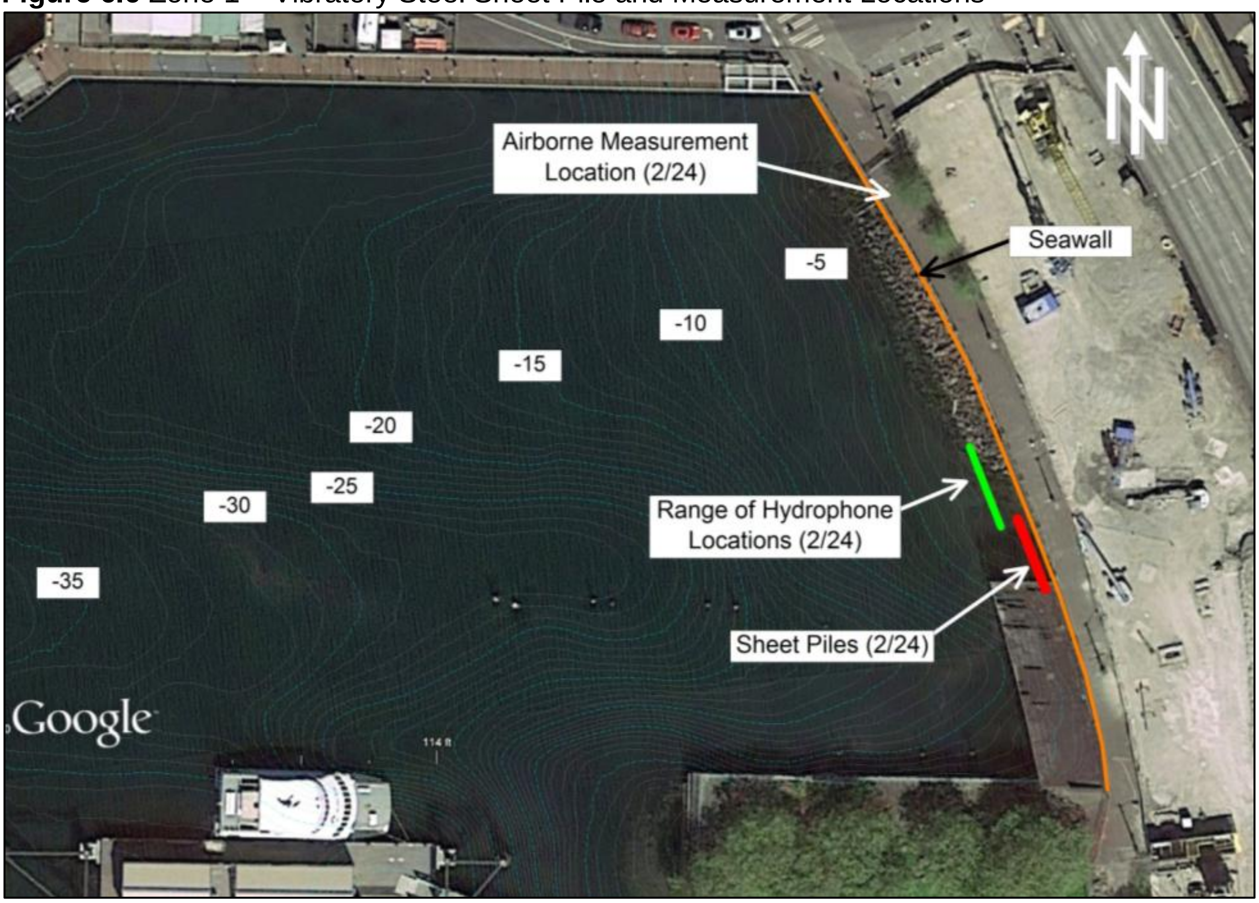
#### 6.2.1.2 Vibratory Steel Sheet Piles

Airborne and underwater measurements were conducted to measure sound generated by vibratory steel pile installation on February 24, 2014. While the first five vibratory sheet piles were also monitored in Zone 4, a clear line of acoustic transmission could not be obtained in Zone 4 due to access restrictions. As a result, National Oceanic and Atmospheric Administration (NOAA) requested additional monitoring in Zone 1 to measure sound levels with a direct line of acoustic transmission between the hydrophone and sheet piles.

Measurements made during vibratory steel pile installation took place north of the sheet piles. Sheet piles were installed beginning to the south and working north throughout the day. The hydrophone was deployed north of the sheet piles and was relocated before each pile drive to maintain a 33 foot (10 meter) distance from the northern edge of the sheet piles. The hydrophone maintained a depth of 3 feet (1 meter) below the surface for the duration of the measurements. A direct line of acoustic transmission was maintained between the hydrophone and the sheet pile being driven. Data was logged continuously with summary periods of 10 seconds.

Figure 6.6 illustrates the locations of the vibratory piles, hydrophone deployment locations and airborne measurement location.

**Figure 6.6** Zone 1 – Vibratory Steel Sheet Pile and Measurement Locations




*Source: The Greenbusch Group, Inc.*

Table 6.3 presents the depth of the hydrophone, water depth, and distance between the hydrophone and the pile.

**Table 6.3** Zone 1 Hydrophone Location Information for Vibratory Sheet Pile Installation

| Sheet | Water Depth | Hydrophone Depth | Distance to Pile |
|---|---|---|---|
| Sheet #1 | ~8 feet | ~3 feet | ~33 feet |
| Sheet #2 | ~8 feet | ~3 feet | ~33 feet |
| Sheet #3 | ~7 feet | ~3 feet | ~33 feet |
| Sheet #4 | ~7 feet | ~3 feet | ~33 feet |
| Sheet #5 | ~7 feet | ~3 feet | ~33 feet |
| Sheet #6 | ~6 feet | ~3 feet | ~33 feet |
| Sheet #7 | ~6 feet | ~3 feet | ~33 feet |

*Source: The Greenbusch Group, Inc.*

### *6.2.2 Zone 4*

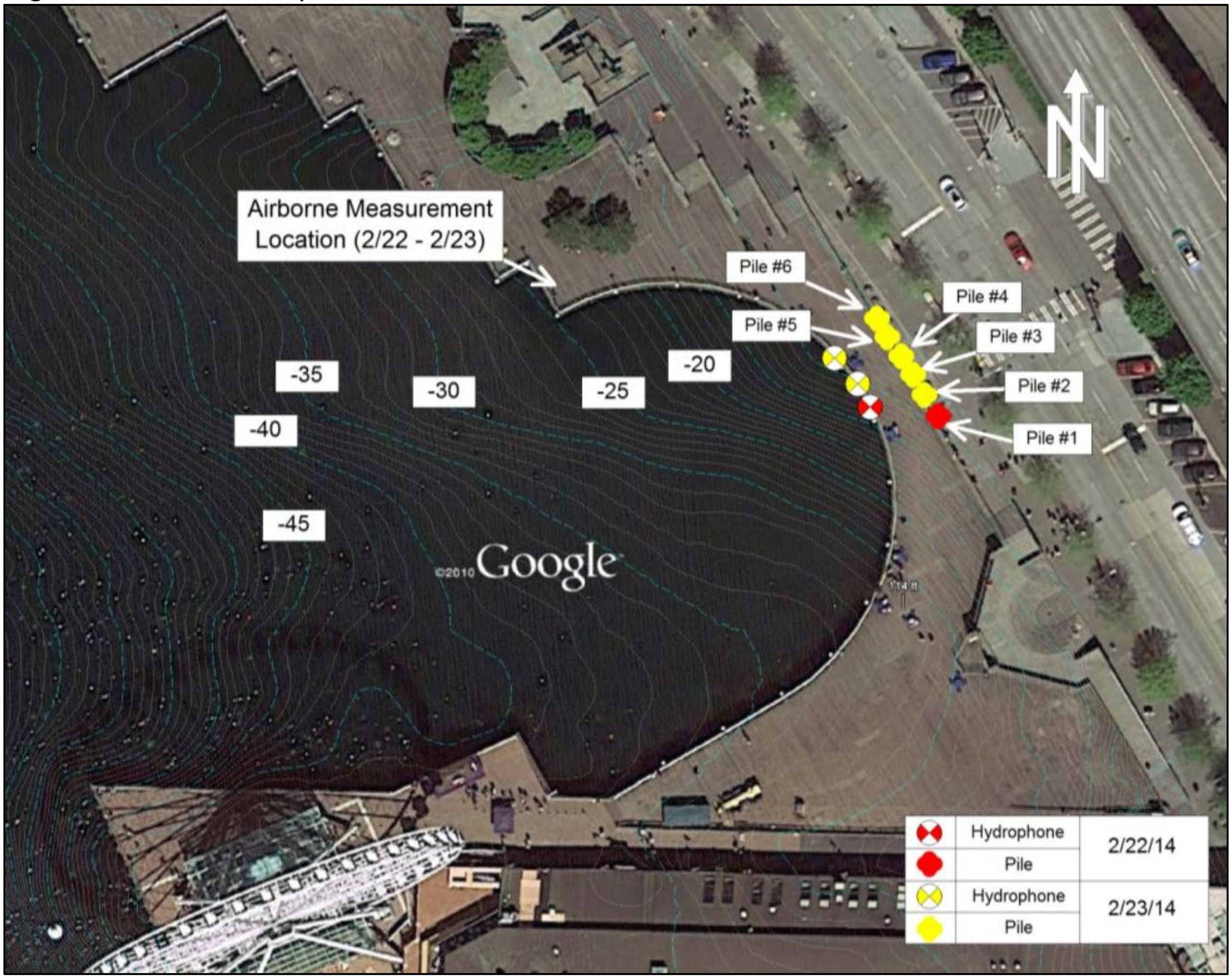
Measurements of impact-driven concrete piles were performed in Zone 4 on February 22 and February 23, 2014. Vibratory sheet pile monitoring was conducted on February 12 and February 13, 2014.

#### 6.2.2.1 Impact-Driven Concrete Piles

The first five concrete piles were monitored in Zone 1, however underwater sound levels exceeded the limits specified in MMPA LOA by as much as 14 dB. Concrete piles in Zone 1 were driven near the intersection of the Seawall and a sheet pile wall located at the south side of Zone 1. Because the piles were driven near the corner of the existing seawall and sheet pile wall, it was unclear if the measured sound levels were being artificially increased by reflections off of these walls. To determine whether the exceedances of sound limits specified in the MMPA LOA measured in Zone 1 were the result of these site specific conditions, measurements were also made during impact driven concrete pile installation in Zone 4.

Measurements of impact-driven concrete piles were performed on February 22 and February 23, 2014. Three hydrophones were used to measure underwater sound levels in Zone 4. Two hydrophones were deployed approximately 33 feet (10 meters) away from the piles. One hydrophone was 3 feet (1 meter) below the surface and the other maintained a depth of approximately 10 feet (3 meters). Water depth near the hydrophone was approximately 12 feet (3.7 meters). Figure 6.7 illustrates the locations of the piles, airborne sound level meter, and hydrophones during impact pile driving in Zone 4.

**Figure 6.7** Zone 4 – Impact-Driven Concrete Pile and Measurement Locations




*Source: The Greenbusch Group, Inc.*

Table 6.4 presents the depth of the hydrophone, water depth, and distance between the hydrophone and the pile.

**Table 6.4** Zone 4 Hydrophone Location Information for Impact-Driven Concrete Piles

| Pile | Water Depth | Hydrophone | Hydrophone Depth | Distance to Pile |
|---|---|---|---|---|
| Pile #1 | ~13 feet | Upper | ~3 feet | ~33 feet |
| | | Lower | ~10 feet | |
| Pile #2 | ~12 feet | Upper | ~3 feet | ~33 feet |
| | | Lower | ~10 feet | |
| Pile #3 | ~12 feet | Upper | ~3 feet | ~33 feet |
| | | Lower | ~10 feet | |
| Pile #4 | ~12 feet | Upper | ~3 feet | ~33 feet |
| | | Lower | ~10 feet | |
| Pile #5 | ~10 feet | Upper | ~3 feet | ~33 feet |
| | | Lower | ~10 feet | |
| Pile #6 | ~10 feet | Upper | ~3 feet | ~33 feet |
| | | Lower | ~10 feet | |

*Source: The Greenbusch Group, Inc.*

#### 6.2.2.2 Vibratory Steel Sheet Piles

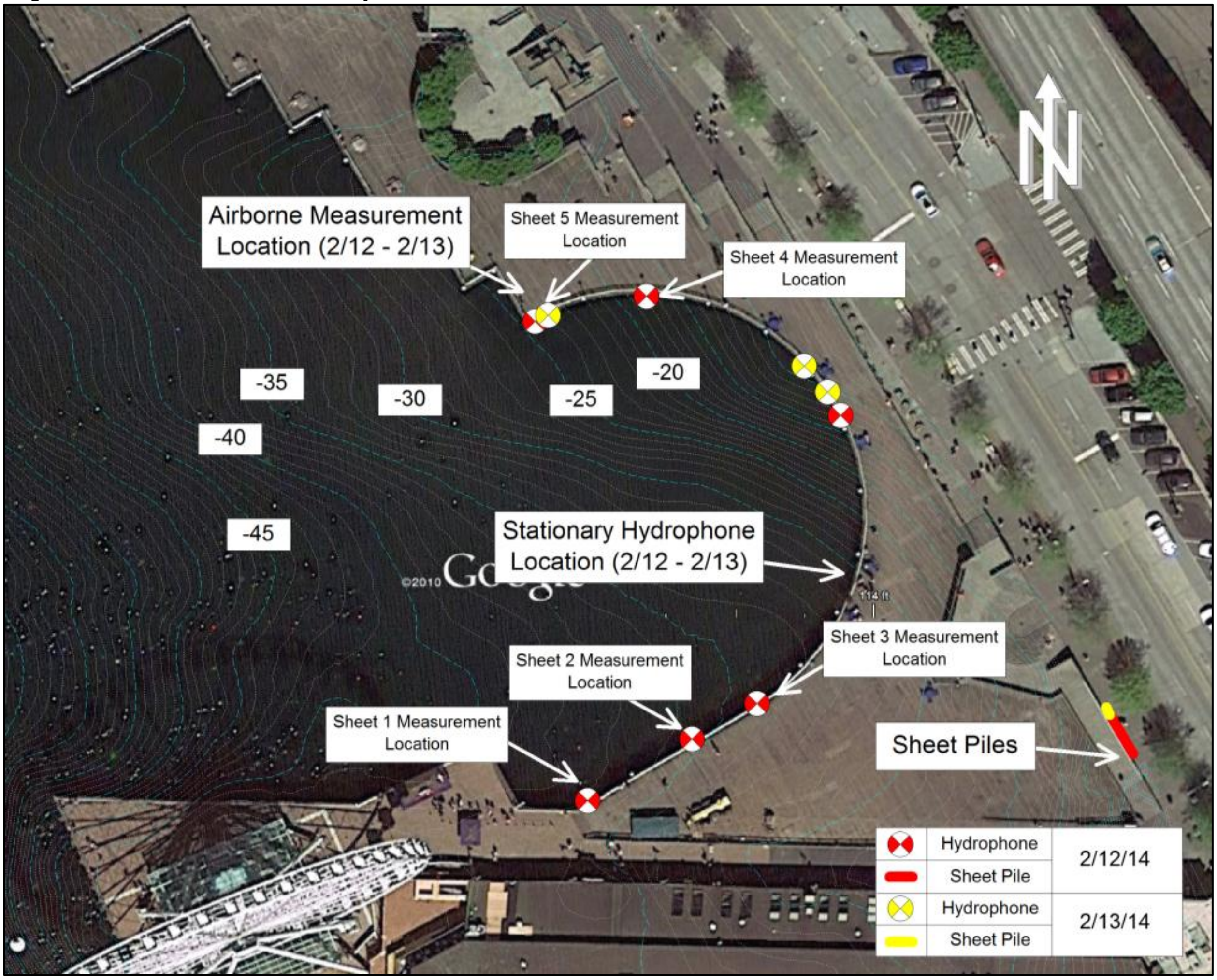
Measurements were conducted for vibratory steel sheet pile installation in Zone 4 on February 12 and February 13, 2014. Two hydrophones were positioned at a depth of 3 feet (1 meter) and two were positioned at 70% to 85% of the total water depth.

During the measurements, one set of hydrophones were positioned as close to the vibratory steel sheet installation as possible, approximately 140 feet (43 meters) away. The other set of hydrophones changed locations between the pile drives to achieve multiple samples at different distances from the piles for calculation of the transmission loss in Zone 4.

The sheet piles were installed on the landward side of the Waterfront Park dock. The existing dock pilings prevented the hydrophones from being deployed to maintain a direct line of acoustic transmission. Further vibratory steel sheet pile measurements were conducted in Zone 1 where a direct line of acoustic transmission was able to be achieved.

Figure 6.8 illustrates the locations of the vibratory piles, hydrophone deployment locations, and airborne measurement locations.

**Figure 6.8** Zone 4 – Vibratory Steel Sheet Pile and Measurement Locations




*Source: The Greenbusch Group, Inc.*

The depths of the hydrophones at each measurement location are presented in Table 6.5.

**Table 6.5** Zone 4 Hydrophone Location for Vibratory Steel Pile Installation

| Sheet Pile Measurement Location | Hydrophone Location | Hydrophone Depth | Distance between Hydrophones | Distance to Piles | Total Water Depth |
|---|---|---|---|---|---|
| Stationary | Upper | ~3 feet | 24 feet | ~112-131 feet | ~38 feet |
| | Lower | ~27 feet | | | |
| Location 1 | Upper | ~3 feet | 29 feet | ~226 feet | ~40 feet |
| | Lower | ~32 feet | | | |
| Location 2 | Upper | ~3 feet | 29 feet | ~180 feet | ~40 feet |
| | Lower | ~32 feet | | | |
| Location 3 | Upper | ~3 feet | 29 feet | ~148 feet | ~45 feet |
| | Lower | ~32 feet | | | |
| Location 4 | Upper | ~3 feet | 29 feet | ~259 feet | ~30 feet |
| | Lower | ~32 feet | | | |
| Location 5 | Upper | ~3 feet | 22 feet | ~282 feet | ~30 feet |
| | Lower | ~25 feet | | | |

*Source: The Greenbusch Group, Inc.*

## 6.3 Pile and Driving Information

Concrete piles were driven with an APE Model D62-42 Single Acting Diesel Impact Hammer with a maximum striking energy of 153,799 foot-pounds. The weight of the ram was 13,671 pounds with a rated stroke of 11.25 feet and generated between 34 and 53 blows per minute. A six inch plywood pile cushion was used on top of the 24-inch concrete piles. A cut sheet of the hammer and pile cushion can be found in the Appendix of this Report.

Steel sheet piles were driven using an APE Model 250VM Vibratory Driver/Extractor operating at 1,750 VPM generating a driving force of 196 US tons. The suspended weight with clamp and 75 feet of hose is 17,500 pounds. A cut sheet of the vibratory driver can be found in the Appendix of this Report.

The following Sections contain information about the piles driven in Zone 1 and Zone 4.

### *6.3.1 Zone 1*

Sound levels were measured for five 56-foot-long, 24-inch-diameter, pre-stressed octagonal concrete piles in Zone 1 between February 17 and February 19, 2014. Piles were driven to a depths ranging between approximately 18 feet to 36 feet (see Table 6.6).

In addition to the five concrete piles, sound levels were also measured for seven pairs of 50-foot-long, 24-inch steel sheet piles on February 24, 2014. Measured sheet piles were driven to a depth of approximately 25 feet (see Table 6.7).

The substrate the concrete and sheet piles were driven into in Zone 1 was hard and rocky.

#### 6.3.1.1 Impact-Driven Concrete Piles

Table 6.6 below presents a summary of the concrete piles which were driven in Zone 1 during airborne and underwater sound monitoring.

**Table 6.6** Zone 1 Impact-Driven Concrete Piles

| Pile Number | Pile Size and Type | Sound Attenuation | Date Driven | Water Depth | Distance to Water's Edge | Depth into Substrate | Number of Strikes |
|---|---|---|---|---|---|---|---|
| 1 | 24" Diameter Concrete | 6" Pile Cushion | 2/17/14 | ~3 feet | ~12 feet | 18 feet | 411 |
| 2 | 24" Diameter Concrete | 6" Pile Cushion | 2/18/14 | ~3 feet | ~12 feet | 25 feet | 482 |
| 3 | 24" Diameter Concrete | 6" Pile Cushion | 2/18/14 | ~3 feet | ~12 feet | 36 feet | 846 |
| 4 | 24" Diameter Concrete | 6" Pile Cushion | 2/19/14 | ~3 feet | ~12 feet | 35 feet | 739 |
| 5 | 24" Diameter Concrete | 6" Pile Cushion | 2/19/14 | ~3 feet | ~12 feet | 30.5 feet | 640 |

*Source: The Greenbusch Group, Inc., Manson Construction, Anchor QEA*

#### 6.3.1.2 Vibratory Steel Sheet Piles

Table 6.7 below presents a summary of the sheet piles which were driven in Zone 1 during airborne and underwater monitoring.

**Table 6.7** Zone 1 Vibratory Steel Sheet Piles

| Sheet Number | Pile Size and Type | Sound Attenuation | Date Driven | Water Depth | Distance from Pile to Water's Edge | Depth into Substrate | Drive Time (min.) |
|---|---|---|---|---|---|---|---|
| 1 | AZ26-700N Pair | None | 2/24/14 | ~3 feet | ~6 feet | 25 feet | 15 |
| 2 | AZ26-700N Pair | None | 2/24/14 | ~3 feet | ~6 feet | 25 feet | 12 |
| 3 | AZ26-700N Pair | Reduced throttle setting | 2/24/14 | ~3 feet | ~6 feet | 25 feet | 22 |
| 4 | AZ26-700N Pair | Reduced throttle setting | 2/24/14 | ~3 feet | ~6 feet | 25 feet | 13 |
| 5 | AZ26-700N Pair | Reduced throttle setting | 2/24/14 | ~3 feet | ~6 feet | 25 feet | 12 |
| 6 | AZ26-700N Pair | Reduced throttle setting | 2/24/14 | ~3 feet | ~6 feet | 25 feet | 12 |
| 7 | AZ26-700N Pair | Reduced throttle setting | 2/24/14 | ~3 feet | ~6 feet | 25 feet | 15 |

*Source: The Greenbusch Group, Inc., Manson Construction, Anchor QEA*

As described in Section 7.1.3 measured underwater sound levels during Pile 1 and Pile 2 exceeded the sound level limits identified in the LOA and ESA Biological Opinion. In response to these exceedances, the energy of the vibratory driver was reduced until compliance with the sound level limits was achieved.

### *6.3.2 Zone 4*

Six 74-foot-long, 24-inch-diameter, pre-stressed octagonal concrete piles were measured in Zone 4 on February 22 and February 23, 2014. Piles were driven to depths ranging from approximately 44 to 52 feet (see Table 6.8).

In addition to the six concrete piles, five pairs of 60-foot-long, 24-inch steel sheet piles were also measured between February 12 and 13, 2014. Measured sheet piles were driven to a depth of approximately 33 feet (see Table 6.9).

The substrate the concrete and sheet piles were driven into in Zone 4 was softer than Zone1.

#### 6.3.2.1 Impact-Driven Concrete Piles

Table 6.8 presents a summary of the concrete piles which were driven in Zone 4 during airborne and underwater sound level monitoring.

**Table 6.8** Zone 4 Impact-Driven Concrete Piles

| Pile Number | Pile Size and Type | Sound Attenuation | Date Driven | Water Depth | Distance from Pile to Water's Edge | Depth into Substrate | Number of Strikes |
|---|---|---|---|---|---|---|---|
| 1 | 24" Diameter Concrete | 6" pile cushion | 2/22/14 | ~4 feet | ~6 feet | 52 feet | 575 |
| 2 | 24" Diameter Concrete | 6" pile cushion | 2/23/14 | ~4 feet | ~6 feet | 48.5 feet | 630 |
| 3 | 24" Diameter Concrete | Reduced fuel setting, 6" pile cushion | 2/23/14 | ~4 feet | ~6 feet | 47 feet | 501 |
| 4 | 24" Diameter Concrete | Reduced fuel setting, 6" pile cushion, new pile cushion inserted part way through drive | 2/23/14 | ~4 feet | ~6 feet | 45 feet | 387 |
| 5 | 24" Diameter Concrete | Reduced fuel setting, 6" pile cushion, new pile cushion inserted part way through drive | 2/23/14 | ~4 feet | ~6 feet | 45 feet | 458 |
| 6 | 24" Diameter Concrete | Reduced fuel setting, two 6" pile cushions installed at beginning of drive | 2/23/14 | ~4 feet | ~6 feet | 44 feet | 433 |

*Source: The Greenbusch Group, Inc., Manson Construction, Anchor QEA*

In response to measured underwater sound levels exceeding the sound level limits identified in the LOA and Biological Opinion by as much as 5 dB on the initial piles, mitigation measures were implemented during the drives of Piles 3 through 6.

During Pile 3, a lower fuel setting was used on the hammer (fuel setting 2), but the sound level measurements showed the peak sound level limits was still exceeded by 3 dB. In response to the exceedance, the Contractor attempted to utilize the lowest fuel setting (fuel setting 1), but was unable to maintain proper operation of the hammer in this condition. Between Pile 3 and Pile 4, maintenance was performed on the hammer and the lowest fuel setting (fuel setting 1) was able to be maintained. During the drive of Pile 4, the lowest fuel setting was used and a new pile cushion was inserted between the pile and the existing cushion partway through the drive. However, the peak level was still exceeded by 3 dB on the first strike after the new cushion was inserted. The remaining pile strikes were all below the peak threshold and it was decided this attenuation technique would be attempted on Pile 5.

Pile 5 and Pile 6 were driven using the same noise attenuation techniques as Pile 4, with the exception that instead of inserting a new pile cushion partway through the drive, Pile 6 started with two 6-inch pads. Pile 5 and Pile 6 were compliant with noise thresholds.

#### 6.3.2.2 Vibratory Steel Sheet Piles

Table 6.9 presents a summary of the sheet piles which were driven in Zone 4 during airborne and hydroacoustic monitoring.

**Table 6.9** Zone 4 Vibratory Steel Sheet Piles

| Sheet Number | Pile Size and Type | Sound Attenuation | Date Driven | Water Depth | Distance from Pile to Water's Edge | Depth into Substrate | Drive Time (min.) |
|---|---|---|---|---|---|---|---|
| 1 | AZ38-700N Pair | None | 2/12/14 | ~4 feet | ~5 feet | 33 feet | 25 |
| 2 | AZ38-700N Pair | None | 2/12/14 | ~4 feet | ~5 feet | 33 feet | 25 |
| 3 | AZ38-700N Pair | None | 2/12/14 | ~4 feet | ~5 feet | 33 feet | 25 |
| 4 | AZ38-700N Pair | None | 2/12/14 | ~4 feet | ~5 feet | 33 feet | 25 |
| 5 | AZ38-700N Pair | None | 2/13/14 | ~4 feet | ~5 feet | 33 feet | 25 |

*Source: The Greenbusch Group, Inc., Manson Construction, Anchor QEA*

## 7.0 RESULTS

Measurement data collected during the pile installations in Zone 1 and Zone 4 was analyzed to determine the extent of underwater sound isopleths, site specific sound attenuation over distance, and the range and average sound levels relative to species specific criteria.

Monitoring results are presented in the Sections below.

### 7.1 Zone 1

The results of airborne and underwater noise measurements from Zone 1 during the impact driving of concrete piles and vibratory installation of steel sheet pile are presented below.

#### *7.1.1 Airborne Sound Levels*

Airborne sound levels measured in Zone 1 are presented as un-weighted levels normalized to a distance of 50 feet from the piles.

**Table 7.1** Zone 1 Airborne RMS Sound Levels, dB re: 20 μPa

| Pile/Sheet Number | Date | Mitigation Type | Maximum RMS[1] |
|---|---|---|---|
| *Impact-Driven Concrete Piles* | | | |
| 1 | 2/17/14 | 6” Pile Cushion | 123 |
| 2 | 2/18/14 | 6” Pile Cushion | 120 |
| 3 | 2/18/14 | 6” Pile Cushion | 126 |
| 4 | 2/19/14 | 6” Pile Cushion | 115 |
| 5 | 2/19/14 | 6” Pile Cushion | 121 |
| *Vibratory Steel Sheet Piles* | | | |
| 1 | 2/24/14 | None | 109 |
| 2 | 2/24/14 | None | 108 |
| 3 | 2/24/14 | Reduced throttle setting | 108 |
| 4 | 2/24/14 | Reduced throttle setting | 107 |
| 5 | 2/24/14 | Reduced throttle setting | 104 |
| 6 | 2/24/14 | Reduced throttle setting | 108 |
| 7 | 2/24/14 | Reduced throttle setting | 110 |

1. *Linear frequency weighting with exponential time constant of 125 milliseconds*

*Source: The Greenbusch Group, Inc.*

As shown in Table 7.1 impact pile driving resulted in higher sound pressure levels when compared to vibratory pile driving. The MMPA LOA does not establish airborne sound level limits.

### *7.1.2 Impact-Driven Concrete Piles*

The results of underwater sound level measurements during impact pile driving in Zone 1 are presented below.

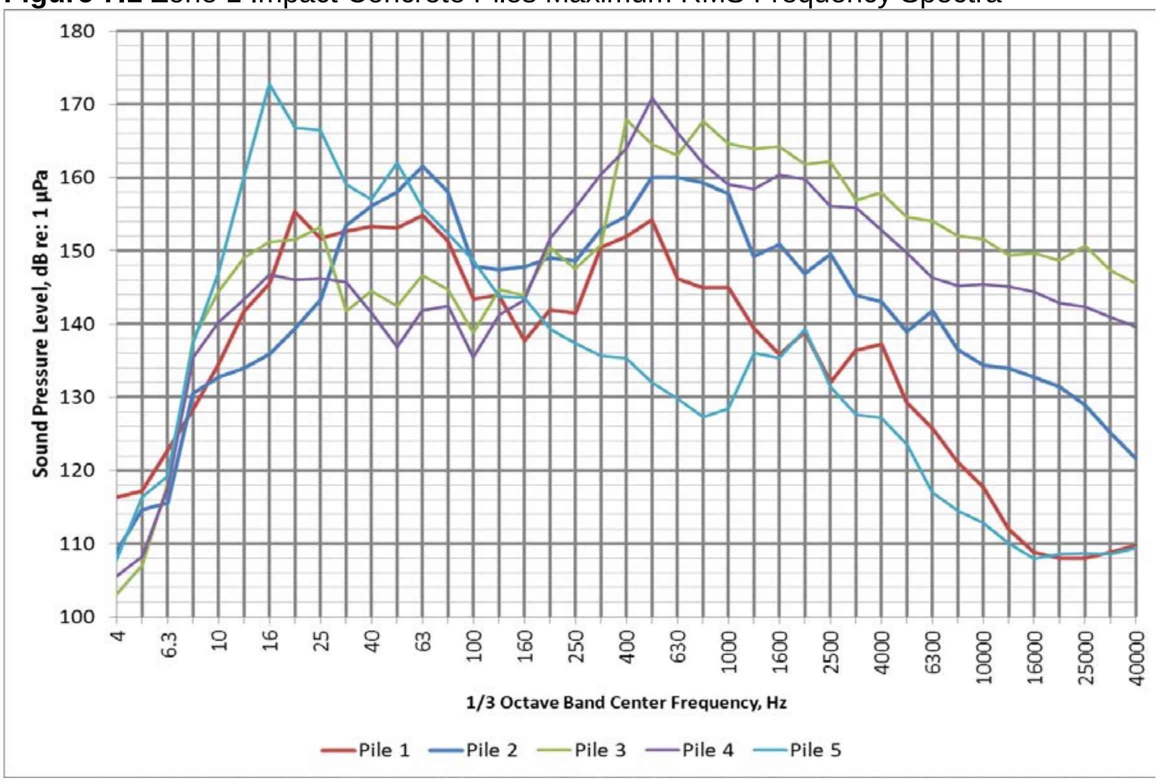
**Table 7.2** Zone 1 Underwater Impact Sound Levels, dB re: 1 μPa

| Pile | Date | Mitigation Type | Peak Strike Levels (limit = 188 dB) | | | RMS Strike Levels (limit = 176 dB) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Max | Min | Avg | Max | Min | Avg |
| 1 | 2/17/14 | 6” Pile Cushion | 190 | 144 | 184 | 179 | 150 | 164 |
| 2 | 2/18/14 | 6” Pile Cushion | 193 | 153 | 187 | 178 | 148 | 166 |
| 3 | 2/18/14 | 6” Pile Cushion | 202 | 149 | 193 | 175 | 149 | 169 |
| 4 | 2/19/14 | 6” Pile Cushion | 199 | 168 | 191 | 174 | 152 | 169 |
| 5 | 2/19/14 | 6” Pile Cushion | 198 | 144 | 181 | 177 | 142 | 171 |

*Source: The Greenbusch Group, Inc.*

Figure 7.1 presents the frequency spectrum for the highest RMS level events measured during Zone 1 impact pile driving.

**Figure 7.1** Zone 1 Impact Concrete Piles Maximum RMS Frequency Spectra




*Source: The Greenbusch Group, Inc.*

### *7.1.3 Vibratory Steel Sheet Piles*

The results of underwater sound level measurements during vibratory pile driving of sheet piles in Zone 1 are presented in Table 7.3 below.

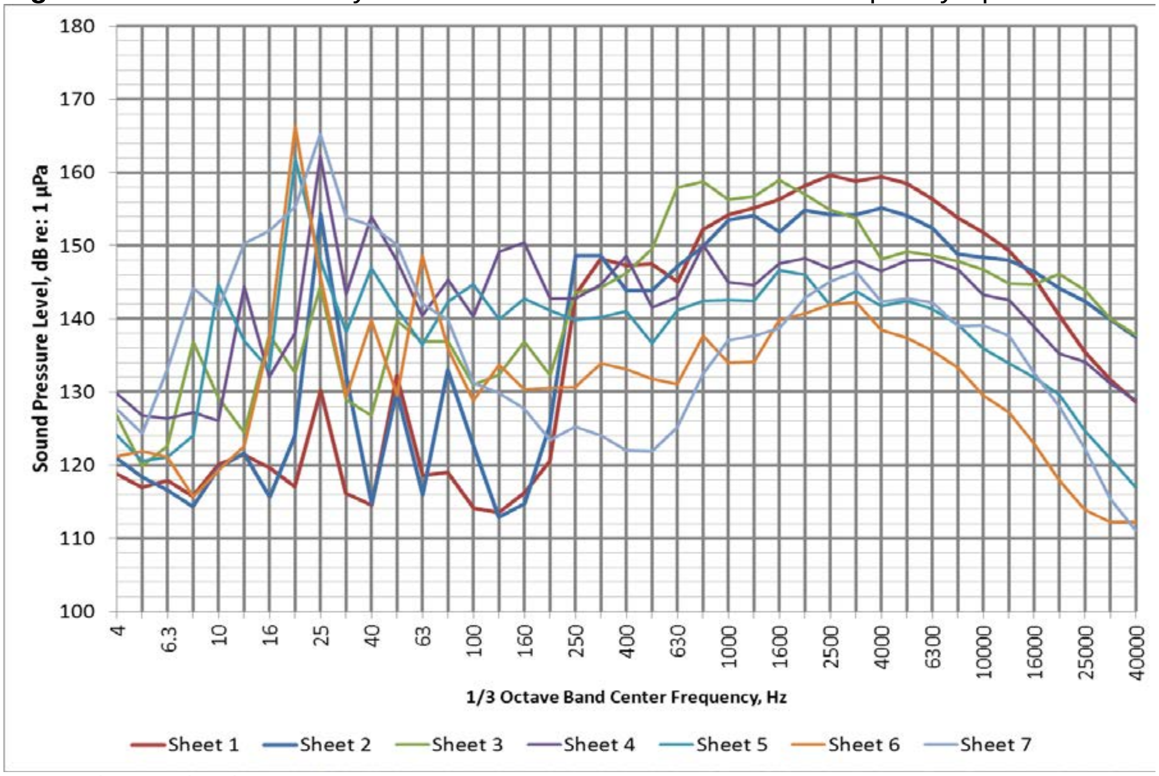
**Table 7.3** Zone 1 Underwater Vibratory Sound Levels, dB re: 1 μPa

| Sheet | Date | Mitigation Type | 10-second Peak Levels (limit = 182 dB) | | | 10-second RMS Levels (limit = 165 dB) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Max | Min | Avg | Max | Min | Avg |
| 1 | 2/24/14 | None | 193 | 148 | 185 | 166 | 138 | 160 |
| 2 | 2/24/14 | None | 187 | 149 | 177 | 165 | 139 | 160 |
| 3 | 2/24/14 | Reduced throttle setting | 188 | 145 | 171 | 167 | 134 | 155 |
| 4 | 2/24/14 | Reduced throttle setting | 178 | 150 | 171 | 165 | 139 | 158 |
| 5 | 2/24/14 | Reduced throttle setting | 177 | 145 | 169 | 163 | 134 | 156 |
| 6 | 2/24/14 | Reduced throttle setting | 178 | 140 | 171 | 166 | 130 | 158 |
| 7 | 2/24/14 | Reduced throttle setting | 179 | 143 | 170 | 167 | 131 | 161 |

*Source: The Greenbusch Group, Inc.*

Figure 7.2 below presents the frequency spectrum for the highest RMS level events measured during Zone 1 vibratory pile driving.

**Figure 7.2** Zone 1 Vibratory Steel Sheet Piles Maximum RMS Frequency Spectra




*Source: The Greenbusch Group, Inc.*

## 7.2 Zone 4

The results of airborne and underwater noise measurements made in Zone 4 during the impact driving of concrete piles and vibratory steel sheet pile installation are presented below.

### *7.2.1 Airborne Sound Levels*

Airborne sound levels measured in Zone 4 are presented as un-weighted levels normalized to a distance of 50 feet from the piles.

#### 7.2.1.1 Airborne Sound Levels from Impact-Driven Concrete Piles and Vibratory Steel Sheet Piles

**Table 7.4** Zone 4 Airborne RMS Sound Levels, dB re: 20 μPa

| Pile/Sheet Number | Date | Mitigation Type | Maximum, RMS[1] |
|---|---|---|---|
| *Impact* | | | |
| 1 | 2/22/14 | 6" pile cushion | 112 |
| 2 | 2/23/14 | 6" pile cushion | 109 |
| 3 | 2/23/14 | Reduced fuel setting, 6" pile cushion | 111 |
| 4 | 2/23/14 | Reduced fuel setting, 6" pile cushion, new pile cushion inserted part way through drive | 110 |
| 5 | 2/23/14 | Reduced fuel setting, 6" pile cushion, new pile cushion inserted part way through drive | 110 |
| 6 | 2/23/14 | Reduced fuel setting, two 6" pile cushions installed at beginning of drive | 110 |
| *Vibratory* | | | |
| 1 | 2/12/14 | None | 124 |
| 2 | 2/12/14 | None | 128 |
| 3 | 2/12/14 | None | 123 |
| 4 | 2/12/14 | None | 120 |
| 5 | 2/13/14 | None | 117 |

1. *Linear frequency weighting with exponential time constant of 125 milliseconds*

*Source: The Greenbusch Group, Inc.*

As shown in Table 7.4, airborne sound pressure levels were higher for vibratory piles than impact piles. The vibratory sheet piles were driven without noise mitigation, which may have resulted in higher sound levels than those produced by the concrete piles. The LOA does not establish airborne sound level limits.

### *7.2.2 Impact-Driven Concrete Piles*

The results of underwater sound level measurements during impact-driven concrete piles in Zone 4 are presented in Table 7.5 below.

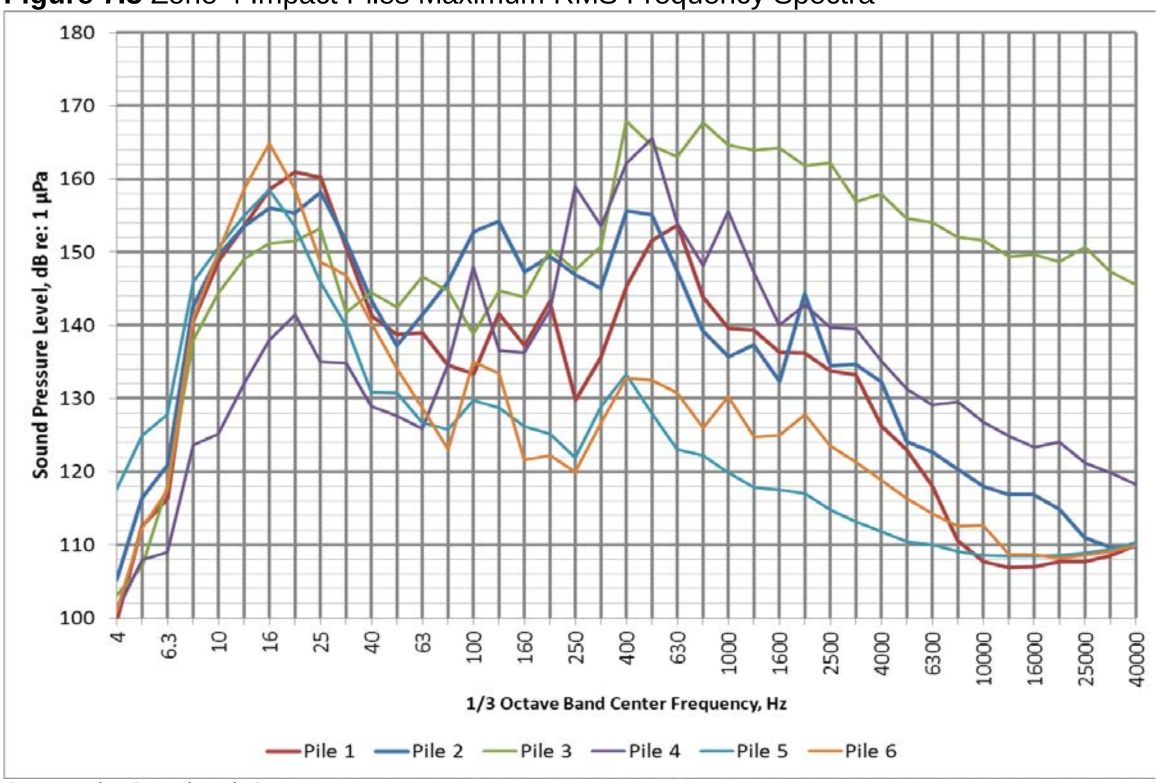
**Table 7.5** Zone 4 Underwater Impact Sound Levels, dB re: 1 μPa

| Pile | Date | Mitigation Type | Peak Strike Levels (limit = 188 dB) | | | RMS Strike Levels (limit = 176 dB) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Max | Min | Avg | Max | Min | Avg |
| 1 | 2/22/14 | 6" pile cushion | 193 | 164 | 182 | 167 | 149 | 164 |
| 2 | 2/23/14 | 6" pile cushion | 187 | 165 | 182 | 167 | 152 | 163 |
| 3 | 2/23/14 | Reduced fuel setting, 6" pile cushion | 191 | 167 | 181 | 167 | 152 | 163 |
| 4 | 2/23/14 | Reduced fuel setting, 6" pile cushion, new pile cushion inserted part way through drive | 191 | 153 | 176 | 171 | 147 | 164 |
| 5 | 2/23/14 | Reduced fuel setting, 6" pile cushion, new pile cushion inserted part way through drive | 179 | 156 | 172 | 166 | 145 | 160 |
| 6 | 2/23/14 | Reduced fuel setting, two 6" pile cushions installed at beginning of drive | 179 | 155 | 171 | 169 | 148 | 161 |

*Source: The Greenbusch Group, Inc.*

Figure 7.3 below presents the frequency spectrum for the highest RMS level events measured during Zone 4 impact pile driving.

**Figure 7.3** Zone 4 Impact Piles Maximum RMS Frequency Spectra




*Source: The Greenbusch Group, Inc.*

### *7.2.3 Vibratory Steel Sheet Piles*

The results of underwater sound level measurements during vibratory pile driving in Zone 4 are presented in Table 7.6 below, normalized to a distance of 10 meters from the piles. While NOAA recommends a typical transmission loss coefficient of 15, field measurements determined a site-specific transmission loss coefficient of 10.5. This site-specific transmission loss coefficient was used to normalize the measured underwater sound levels to the values at 10 meters. Overall, the pier support piles in Zone 4 did not appear to significantly influence measured underwater sound levels.

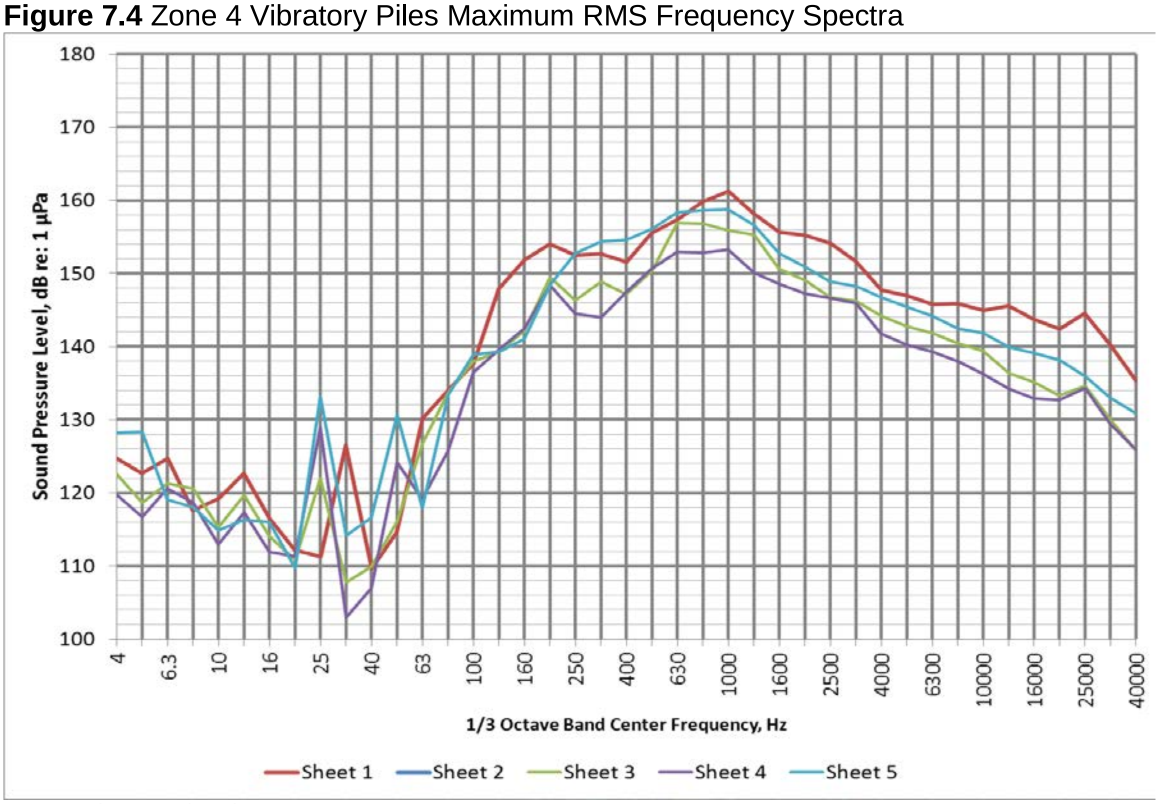
**Table 7.6** Zone 4 Underwater Vibratory Sound Levels, dB re: 1 μPa

| Sheet | Date | Mitigation Type | 10-second Peak Levels (limit = 182 dB) | | | 10-second RMS Levels (limit = 165 dB) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Max | Min | Avg | Max | Min | Avg |
| 1 | 2/12/14 | None | 186 | 143 | 162 | 168 | 132 | 145 |
| 2 | 2/12/14 | None | 179 | 146 | 165 | 158 | 134 | 145 |
| 3 | 2/12/14 | None | 181 | 145 | 164 | 165 | 133 | 149 |
| 4 | 2/12/14 | None | 178 | 144 | 163 | 161 | 132 | 147 |
| 5 | 2/13/14 | None | 186 | 146 | 176 | 166 | 138 | 160 |

*Source: The Greenbusch Group, Inc.*

Figure 7.4 presents the frequency spectrum for the highest RMS level events measured during Zone 4 vibratory pile driving, normalized to a distance of 10 meters from the piles.

**Figure 7.4** Zone 4 Vibratory Piles Maximum RMS Frequency Spectra




*Source: The Greenbusch Group, Inc.*

### 7.3 Marine Mammal Detection Distances

NOAA has established sound thresholds for marine mammals. These thresholds are defined for disturbance and injury, and are based on RMS values. These thresholds are presented in Table 7.7.

**Table 7.7** Marine Mammal Detection Thresholds, dB re: 1 µPa (RMS)

| Functional Hearing Group | Species | Underwater Noise Thresholds | | |
|---|---|---|---|---|
| | | Vibratory Pile Driving Disturbance Threshold | Impact Pile Driving Disturbance Threshold | Injury Threshold |
| Cetaceans | Harbor Porpoise | 120 | 160 | 180 |
| | Dall's Porpoise | | | |
| | Killer Whale | | | |
| | Gray Whale | | | |
| | Humpback Whale | | | |
| Pinnipeds | Harbor Seal | 120 | 160 | 190 |
| | California Sea Lion | | | |

*Source: NOAA*

Based on the marine mammal detection thresholds, the distances for sound generated by pile driving activities to reach the disturbance thresholds for each functional hearing group were calculated. Distances were calculated from the maximum RMS values for vibratory and impact piles using the "practical spreading loss" currently used by WSDOT and NOAA. The distances are presented in Table 7.8 below.

**Table 7.8** Distances to Marine Mammal Detection Thresholds, Meters

| Functional Hearing Group | Distance to Disturbance Threshold | | | | | |
|---|---|---|---|---|---|---|
| | Vibratory Sheets (120 dB) | | | Impact Piles (160 dB) | | |
| | Max | Min | Avg | Max | Min | Avg |
| *Zone 1* | | | | | | |
| Cetaceans | 13,673 | 7,399 | 11,188 | 186 | 86 | 134 |
| Pinnipeds | 13,673 | 7,399 | 11,188 | 186 | 86 | 134 |
| *Zone 4* | | | | | | |
| Cetaceans | 15,941 | 3,434 | 9,321 | 54 | 25 | 35 |
| Pinnipeds | 15,941 | 3,434 | 9,321 | 54 | 25 | 35 |

*Source: The Greenbusch Group, Inc.*

## 7.4 Background Sound Level Distances

Background sound levels were measured in Zone 1 and Zone 4 in the absence of in-water pile installation. Table 7.9 below presents the results of measured underwater background sound levels in Zone 1 and Zone 4.

**Table 7.9** Measured Background Underwater Sound Levels, dB re: 1 μPa (RMS)

| Zone | Maximum | Minimum | Average |
|---|---|---|---|
| 1[1] | 215 | 106 | 163 |
| 4[2] | 140 | 132 | 135 |

1. Results from long term monitoring data. Proximity to Coleman Dock, and active ferry terminal, was expected to contribute to the ambient levels in this area.
2. Results from short-term monitoring data.

*Source: The Greenbusch Group, Inc.*

As shown in Table 7.9 above, the average sound level in Zone 1 is 43 dB above the 120 dB disturbance threshold for Pinnipeds and Cetaceans.

The distances required to reach the average background sound levels are presented in Table 7.10 below.

**Table 7.10** Distances to Background Sound Levels, Meters

| Functional Hearing Group | Distance to Disturbance Threshold | | | | | |
|---|---|---|---|---|---|---|
| | Vibratory | | | Impact | | |
| | Min | Max | Avg | Min | Max | Avg |
| Zone 1 | 10 | 19 | 15 | 47 | 544 | 215 |
| Zone 4 | 343 | 1,594 | 932 | 1,173 | 2,527 | 1,610 |

*Source: The Greenbusch Group, Inc.*

## 7.5 Marine Mammal Monitoring

Monitors observed California sea lions and harbor seals; however these animals did not exhibit any changes in behavior. Details of mammal monitoring are presented in a separate report.

## 8.0 APPENDIX

**Figure A1.** Impact Pile Driver Information

# APE Model D62-42 Single Acting Diesel Impact Hammer

*D62-42 in a stand-off driving Kingpile.*

## MODEL D62-42 (6.2 metric ton ram)

**SPECIFICATIONS**

| | |
|---|---|
| Stroke at maximum rated energy | 135 in (343 cm) |
| Maximum rated energy (Setting 4) | 153,799 ft-lbs (207.63 kNm) |
| Setting 3 | 127,653 ft-lbs (172.33 kNm) |
| Setting 2 | 101,507 ft-lbs (137.03 kNm) |
| Minimum rated energy (Setting 1) | 76,899 ft-lbs (103.81 kNm) |
| *(Variable throttle allows for infinite fuel settings)* | |
| Maximum obtainable stroke | 157 in (381 cm) |
| Maximum obtainable energy | 178,862 ft-lbs (243 kNm) |
| Speed (blows per minute) | 34-53 |

**WEIGHTS**

| | |
|---|---|
| Ram | 13,671 lbs (6,200 kg) |
| Anvil | 2,425 lbs (1,100 kg) |
| Anvil cross sectional area | 367.94 in² (2373.80 cm²) |
| Hammer weight (includes trip device) | 29,100 lbs (13,300 kg) |
| Typical operating (weight with DB32 and pipe insert) | 34,402 lbs (15,602 kg) |

**CAPACITIES**

| | |
|---|---|
| Fuel tank (runs on diesel or bio-diesel) | 25.5 gal (96.52 liters) |
| Oil tank | 8.2 gal (31 liters) |

**CONSUMPTION**

| | |
|---|---|
| Diesel or Bio-diesel fuel | 5.2 gal/hr (19.68 liters/hr) |
| Lubrication | 0.52 gal/hr (1.96 liters/hr) |
| Grease | 8 to 10 pumps every 45 minutes of operation time. |

*Optional Variable Throttle Control.*

**STRIKER PLATE**

| | |
|---|---|
| Weight | 1,036 lbs (470 kg) |
| Diameter | 25 in (57.15 cm) |
| Area | 491 in² (3167.74 cm²) |
| Thickness | 8 in (20.32 cm) |

**CUSHION MATERIAL**

| | |
|---|---|
| Type/Qty | Micarta / 2 each |
| Diameter | 25 in (57.15 cm) |
| Thickness | 1 in (25.4 mm) |
| Type/Qty | Aluminum / 3 each |
| Thickness | 1/2 in (12.7 mm) |
| Diameter | 25 in (57.15 cm) |
| Total Combined Thickness | 3.5 in (8.89 cm) |
| Area | 491 in² (3167.74 cm²) |
| Elastic-modulus | 285 ksi (1,965 mpa) |
| Coeff. of restitution | 0.8 |

*Drive Base Assembly.*

**DRIVE CAP**

| | |
|---|---|
| DB 32: | 2,436 lbs (1,104 kg) |

**INSERT WEIGHT**

| | |
|---|---|
| H-Beam insert for 12" (305 mm) and 14" (355 mm): | 948 lbs (430 kg) |
| Large pipe insert for sizes 12" to 24" diameter: | 1,830 lbs (830 kg) |

**MINIMUM BOX LEAD SIZE/OPERATING LENGTH**

| | |
|---|---|
| Minimum box leader size | 8 in x 32 in (20.32 cm x 81.28 cm) |
| Operating length as described above | 374 in (949.96 cm) |

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**Kent, Washington 98032 USA**
**(800) 248-8498 & (253) 872-0141**
**(253) 872-8710 Fax**

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**www.apevibro.com**
**e-mail: ape@apevibro.com**

*Note: All specifications are subject to change without notice 08/20/2012*

**Figure A2.** Vibratory Pile Driver Information

APE Model 250VM Vibratory Driver/Extractor

| SPECIFICATIONS | DATA |
|---|---|
| Eccentric Moment | 4,500 in-lbs (52 kgm) |
| Frequency | 1,750 VPM |
| Driving Force @ 1,750 VPM | 196 US tons (177.8 tons) |
| Driving Force @ 1,950 VPM | 243 US tons (220.4 tons) |
| Amplitude without Attachment | 0 to 1.25 in ( 32 mm) |
| Max Line Pull | 150 US tons (136.1 tons) |
| Suspended Weight w/ Clamp and 75 ft Hose | 17,500 lbs (7,936 kg) |
| Dynamic Weight w/ Clamp | 9,625 lbs (4,365 kg) |
| Length | 125 in (318 cm) |
| Width at Throat | 14 in (35 cm) |
| Width | 17 in (43 cm) |
| Height | 100 in (254 cm) |
| Hydraulic Hose Length | 150 ft (45 m) |
| Hydraulic Hose Weight 50 ft with Oil | 2,000 lbs (907 kg) |


| SPECIFICATIONS | DATA |
|---|---|
| Power Unit Engine | C18 ACERT Tier III Certified |
| Hydraulic Tank (reserve) | 60 gal (227 L) |
| Hydraulic Tank (main) | 475 gal (1798 L) |
| Fuel Capacity | 165 gal (625 L) |
| Clamp Flow | 10 gpm (41 lpm) |
| Clamp Pressure (sheet clamp) | 310 bar (4500 psi) |
| Maximum Hyd. Flow-Reverse | 0-196 gpm (0-741.86 lpm) |
| Maximum Hyd. Flow-Forward | 0-215 gpm (0-813.78 lpm) |
| Maximum Drive Pressure | 4500 psi (310 bar) |
| Maximum Power | 700 hp (514.86 kW) |
| Operating Speed | 800 to 2100 rpm |
| Height | 94 in (238.76 cm) |
| Width | 82.25 in (208.92 cm) |
| Length | 152 in (386.08 cm) |
| Weight | 19,000 lbs (8618.26 kg) |