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Seattle Multimodal Terminal at Colman Dock

Submittal Template

Title	Phase 3 Hydroacoustic Monitoring Final Report
Subcontractor	Pacific Pile & Marine
Spec Section	General Conditons. 1-07.6(6)
Paragraph No.	General Conditons. 1-07.6(6)
Drawing Ref.	N/A
Resubmittal (provide previous H-P submittal number)	N/A
Submittal Description: Please provide brief outline of inclusions or exclusions of submittal Including building location	The attached contains the Phase 3 Hyrdoacoustic Monitoring Final Report prepared by The Greenbusch Group.

HOFFMAN CONSTRUCTION COMPANY
This submittal has been reviewed for general conformance with the contract documents. Contractor's review does not relieve the Vendor/Subcontractor of responsibility for compliance with all requirements of the contract, including completeness and accuracy of this submittal.

Bryan Lammers
5/13/20 087.6- 1-07.6(6)
Date Submittal #

Pacific Pile & Marine

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TRANSMITTAL

TO: Hoffman Pacifc, A Joint Venture
600 Stewart Street
Suite 1000
Seattle, WA 98108

DATE: 05/13/2020

RE: Phase 3 Hydroacoustic Monitoring Final Report

ATTN: Bryan Lammers, Brandon Brody-Heim

PROJECT: 9074 – Seattle Ferry Terminal at Colman Dock MACC

WE ARE SENDING YOU: ☐ Herewith ☐ Under Separate Cover ☐ Certs
☒ Submittal ☐ Shop Drawings ☐ Other ______

QUANTITY	DESCRIPTION
1	PPM Submittal 21.15 – Phase 3 Hydroacoustic Monitoring Final Report– General Conditons. 1-07.6(6)
1	Phase 3 Hydroacoustic Monitoring Final Report

THESE ITEMS ARE TRANSMITTED AS CHECKED BELOW:

☒ For approval. Please return **1** copy with approval and any correction notations.

☐ Revised & for final approval. Please return ______ copies.

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☐ For pricing only. Do not proceed with construction until notified.

☐ Change Order to your contract will follow with these documents.

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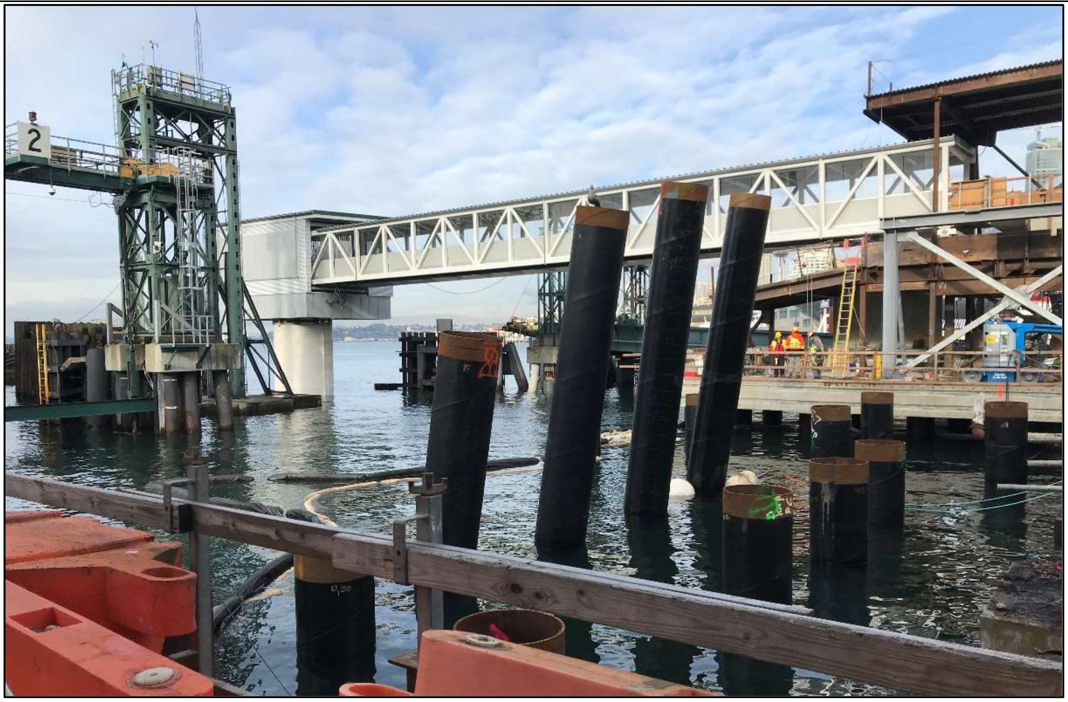
Sincerely,
PACIFIC PILE & MARINE, L.P.



COLMAN DOCK SEASON 3
HYDROACOUSTIC MONITORING REPORT

May 13, 2020

Prepared For:

Pacific Pile & Marine

Prepared By:

THE GREENBUSCH GROUP, INC.

1900 West Nickerson Street Suite 201
Seattle, Washington 98119

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1.0 EXECUTIVE SUMMARY

This Hydroacoustic Monitoring Report presents the results of underwater (hydroacoustic) and airborne sound level measurements made between November 2019 and February 2020 during the installation of 24-inch and 36-inch steel pipe piles with diesel impact hammers. This monitoring was conducted during Season 3 of the Seattle Multimodal Terminal at Colman Dock (Project).

Average unweighted underwater 90% RMS (RMS_{90}) sound levels measured approximately 33 feet (10 meters) from impact pile driving ranged between 170 and 183 dB re: 1 μPa for 36-inch diameter piles driven below the waterline, 155 and 159 dB re: 1 μPa for 36-inch piles driven on-land. The average unweighted RMS_{90} sound level from a 24-inch diameter Wedge Pile was 168 dB re: 1 μPa. Average peak sound levels from 36-inch piles driven below the waterline ranged between 180 and 196 dB re: 1 μPa, 162 and 165 dB re: 1 μPa from 36-inch piles driven above the waterline. The 24-inch Wedge Pile generated an unweighted average peak sound level of 179 dB re: 1 μPa.

Based on the highest average peak and daily cSEL levels measured by the far-field hydrophone, the distance required for sound to dissipate to below marine mammal injury thresholds (Level A) are estimated to be 16,442 feet (5,011 meters) for high-frequency cetaceans, up to 194 feet (59 meters) for other cetaceans, and 92 feet (28 meters) for pinnipeds. RMS_{90} sound levels are estimated to dissipate to below the 160 dB marine mammal disturbance threshold (Level B) after 852 feet (260 meters).

2.0 INTRODUCTION

The Project Specifications and the Underwater Noise Monitoring Plan issued by the Washington State Department of Transportation (WSDOT), dated July 27, 2016 include requirements for hydroacoustic monitoring. These requirements include the number of piles to be monitored, monitoring equipment, signal processing requirements, measurement locations, analysis methodology, and information required to be reported to the Services. This Hydroacoustic Monitoring Report fulfills the Project's hydroacoustic monitoring and reporting requirements.

The Project is located west of Alaskan Way between Marion Avenue and Yesler Way in downtown Seattle, Washington (see Figure 2.1). Underwater and airborne sound level measurements were conducted between November 2019 and February 2020.

Figure 2.1 Vicinity Map of Seattle Multimodal Terminal at Colman Dock Project

3.0 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, logarithmic scale.

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:

- **A-Weighted Decibel (dBA)**

  The human ear has a unique response to sound pressure. It is less sensitive to those sounds falling outside the speech frequency range. Sound level meters and monitors utilize a filtering system to approximate human perception of sound. Measurements made utilizing this filtering system are referred to as “A weighted” and are called “dBA”.

- **Equivalent Sound Level (L_{eq})**

  Equivalent Sound Level is the level of a constant sound having the same energy content as the actual time-varying level during a specified interval. The L_{eq} is used to characterize complex, fluctuating sound levels with a single number.

- **Maximum Sound Level (L_{max})**

  L_{max} is the maximum recorded root mean square (rms) A-weighted sound level for a given time interval or event. L_{max} can be defined for two time weightings, “slow” and “fast.” “Slow” uses 1-second time constant, and “fast” uses a 125-millisecond time constant. For transient events of very short duration, L_{max} “fast” will be greater than L_{max} “slow.” This report utilized L_{max} “fast”.

- **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).

- **Percent Sound Level (L_n)**

  Percent Sound Level is the sound level that is exceeded n percent of the time; for example, L_{08} is the level exceeded 8% of the time. L_{25} is the sound level exceeded 25% of the time. This report utilizes the L_{90} and L_{95} descriptors.

- **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 sound pressure impact on marine mammals.

- **90% Root Mean Square (RMS_{90})**

  The RMS_{90} level is used for the analysis of impact pile driving and is the RMS level containing 90 percent of the energy in a pile strike. The RMS_{90} energy is established between the 5% and 95% of the pile energy and is calculated for each pile strike.

- **Sound Exposure Level (SEL)**

  The SEL is the squared sound pressure integrated or summed over time, referenced to a standard pressure squared (20 μPa for airborne and 1 μPa for underwater), normalized to one second, and converted to decibels.

- **Cumulative Sound Exposure Level (cSEL)**

  The cSEL is the SEL accumulated over time. In this report cSEL is calculated by combining the single strike SEL values for each pile.

4.0 HYDROACOUSTIC MONITORING AND REPORTING REQUIREMENTS

Requirements for the Project's hydroacoustic monitoring, signal processing, and reporting are included in the Project Specifications dated July 21, 2017; the Seattle Multimodal Terminal at Colman Dock-Phase 1 Underwater Noise Monitoring Plan authored by WSDOT dated July 27, 2016; and the Colman Dock Phase 3 Underwater Noise Monitoring Plan issued by The Greenbusch Group, Inc. dated August 12, 2019. Underwater sound level limits are not included in either the Project Specifications or the Underwater Noise Monitoring Plans authored by WSDOT and Greenbusch.

4.1 Project Specifications

Section 00 72 00 1-07.6(6) of the Project Specifications includes the following underwater noise monitoring requirements for the Contractor:

- The Contractor will comply with the provisions of the Underwater Noise Monitoring Plan authored by WSDOT. To comply with the WSDOT Underwater Noise Monitoring Plan, the Contractor will conduct hydroacoustic monitoring during construction to document the sound transmission during impact pile driving of steel piles.
- A representative subset of impact driven steel piles will be monitored at the start of each in-water work season, per the noise monitoring plan.
- Underwater sound levels will be continuously monitored for the entire duration of each pile being driven.
- The Contractor shall provide qualified staff and appropriate equipment to conduct impact driven steel pile hydroacoustic monitoring. Only staff with appropriate hydroacoustic expertise, as approved by the Contracting Agency, shall perform this monitoring.

4.2 WSDOT Underwater Noise Monitoring Plan

The Underwater Noise Monitoring Plan issued by WSDOT includes requirements regarding the number of piles to be monitored, hydroacoustic monitoring equipment, signal processing requirements, measurement locations, analysis methodology and information required to be reported to the Services.

The WSDOT Underwater Noise Monitoring Plan requires hydroacoustic monitoring locations to be 33 feet (10 meters) away from the pile at mid water depth and 3H, where H is the water depth of the pile being monitored. The 3H hydrophone should be at 80% of the water depth at the measurement location. Monitoring locations are required to have a clear acoustic line-of-sight between the pile and the hydrophones.

Sound levels measured at these locations must include the frequency spectrum, ranges, means, and L_{50} for peak, RMS_{90} and SEL_{90} sound pressure levels for each marine mammal functional hearing group as well as the broadband sound pressure levels. L_{50} levels reported in this document are the median sound levels from each pile drive. The estimated distance at which peak, RMS and cSEL values exceed the respective threshold values must also be reported.

Airborne sound level measurements are required to be made between 50 feet and 200 feet from impact pile driving. Notes are also required to be made to document any anomalous noise events such as boats and low flying aircraft that could influence the measurements and these events must be excluded from the measurement results. Ambient airborne sound levels must also be made for at least 15 minutes in the absence of construction activities to document background sound levels. The results of airborne sound monitoring must include the frequency spectrum, L_{max}, L_{eq}, and L_{90} for each pile including time history plots and an estimation of the received sound levels at the nearest residences.

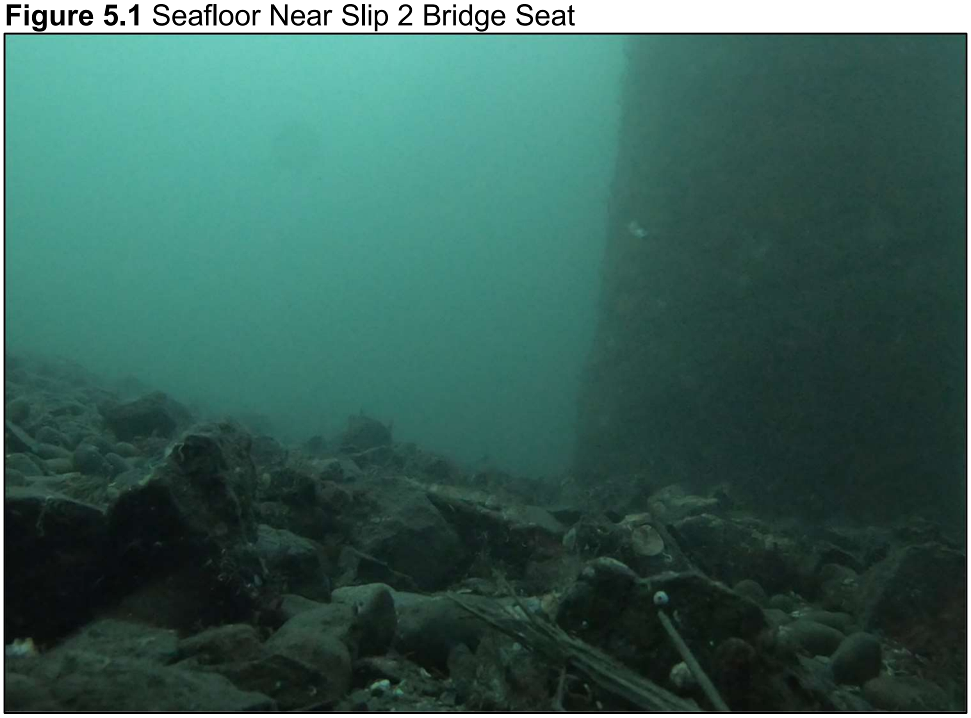
4.3 Greenbusch Underwater Noise Monitoring Plan

The Colman Dock Phase 3 Underwater Noise Monitoring Plan authored by the Greenbusch Group, Inc. was prepared based on the requirements of the Project Specifications and the WSDOT Underwater Noise Monitoring Plan and provides details of how the hydroacoustic monitoring will be implemented. The Greenbusch Underwater Noise Monitoring Plan includes specific types of equipment that will be used during the monitoring, the resumes of hydroacoustic monitoring staff and a discussion of which piles will be monitored.

5.0 PILE AND PILE DRIVING EQUIPMENT INFORMATION

During Season 3, all steel pipe piles were initially driven with a vibratory hammer and then proofed with a diesel impact hammer. The piles for the Wedge Pilings are 24-inch diameter steel pipe piles with a wall thickness of 5/8-inch. The Wedge Piling measured during Season 3 (Pile W1) was approximately 82-feet long. North Trestle and Slip 2 Bridge Seat piles are 36-inch diameter steel pipe piles with wall thicknesses of 1-inch. Piles measured at the North Trestle ranged in length from approximately 70-feet to 97-feet. The Slip 2 Bridge Seat piles were battered piles and were approximately 105-feet long. The substrate is primarily composed of sand, shell hash, silt and includes some gravel and cobble. A photo of the seafloor near the Slip 2 Seat Piles is shown in Figure 5.1.

Figure 5.1 Seafloor Near Slip 2 Bridge Seat



Measured piles driven at the west side of the North Trestle (North Trestle Group B) and the Slip 2 Bridge Seat were driven with an APE D100-52 diesel impact hammer with an energy rating of 248,063 foot-pounds. The ram weighed 22,050 pounds with a stroke length of 11.25 feet. A cut sheet of the APE D100-52 diesel impact hammer can be found in the Appendix of this Report.

All other piles installed during hydroacoustic monitoring were driven using an APE D62 diesel impact hammer. The APE D62 has a maximum energy rating of 162,052 foot-pounds, a ram weight of 13,671 pounds and a stroke length of 12 feet. Specifications for the APE D62 are shown in the Appendix.

Table 5.1 provides a summary of the steel pipe piles driven with impact pile drivers during the measurements.

Table 5.1 Summary Pipe Piles, Feet (Meters)

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Embedment[1]	Number of Strikes[2]
West Side of North Trestle (North Trestle Group B)						
N12.5-NF	11/8/2019	Bubble Curtain	274 (84)	28 (9)	56 (17)	550
N11-NC.7	12/4/2019	Bubble Curtain	284 (87)	41 (13)	49 (15)	267
N12-NC.7	12/4/2019	Bubble Curtain	310 (95)	43 (13)	49 (15)	234
Slip 2 Bridge Seat (battered piles)						
Pile 4	1/17/2020	Bubble Curtain	395 (120)	43 (13)	59 (18)	511
Pile 3	1/17/2020	Bubble Curtain	393 (120)	41 (13)	59 (18)	731
Pile 2	1/17/2020	Bubble Curtain	389 (119)	38 (12)	59 (18)	629
Pile 1	1/17/2020	Bubble Curtain	384 (117)	38 (12)	59 (18)	328
Wedge Piling						
W1	2/26/2020	Bubble Curtain	165 (50)	30 (9)	35 (11)	197
East Side of North Trestle (North Trestle Group A)						
E1.1-10 (on-land)	2/26/2020	On-Land	15 (5)	N/A	60 (18)	831
E1.1-8 (on-land)	2/26/2020	On-Land	15 (5)	N/A	61 (19)	366
E3-5	2/26/2020	Bubble Curtain	25 (8)	6 (2)	67 (20)	742

1. N12.5-NF and N11-NC.7 embedment depths listed on pile logs. N12-NC.7 was extrapolated from nearby piles. Embedment of all other piles were estimated from water depth and information found on the Project Drawings.
2. Number of strikes included in analysis.

During hydroacoustic monitoring an unconfined bubble curtain was used during all impact pile driving. The unconfined bubble curtain consisted of six 2.5-inch nominal diameter aluminum rings with four rows of 1/16th inch diameter bubble release holes in the axial direction. Photos of the unconfined bubble curtain are shown in Figure 5.2 and Figure 5.3. The system design calculations and drawings of the bubble curtain are provided in the Appendix.

Figure 5.2 Bubble Curtain

Figure 5.3 Operating Bubble Curtain

6.0 MEASUREMENT METHODOLOGY

6.1 Equipment

The hydroacoustic and airborne monitoring equipment used during Season 3 are identified in Table 6.1 and Table 6.2.

Table 6.1 Hydroacoustic Monitoring Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2250	1	Sound Level Analyzer	3006756
Reson TC-4013	2	Hydrophone	2513032
			0712213
Brüel & Kjaer Type 2647-A	2	Charge Converter (1 mV/pC)	2638259
			2582112
Brüel & Kjaer 1704-A-002	1	Signal Conditioner	101161
G.R.A.S. Type 42AC	1	Pistonphone	201835
Tascam DR-100MKIII	1	Digital Audio Recorder	1690316

Table 6.2 Airborne Monitoring Equipment

Make and Model	Quantity	Description	Serial Number
Svantek 979	1	Sound Level Analyzer	46177
Svantek SV17	1	Preamplifier	57824
G.R.A.S. 40AE	1	Microphone	258193
Larson Davis CAL200	1	Acoustic Calibrator	16828
Svantek 307	1	Sound Level Analyzer	78646
Svantek ST30	1	Microphone	82620
Larson Davis CAL200	1	Acoustic Calibrator	16826

Monitoring equipment was factory calibrated within 1 year of the measurement date. Calibration tones were also recorded before and after each day of monitoring for verification of calibration factors during post-processing. Hydrophones were calibrated using the G.R.A.S. pistonphone and microphones were calibrated with the Larson Davis CAL200 acoustic calibrators.

Underwater sound levels were measured using two Reson TC-4013 hydrophones connected to the Brüel & Kjaer Type 2647-A charge converters and Brüel & Kjaer 1704-A-002 signal conditioner. The signal conditioner was connected to the Tascam DR-100KMIII digital audio recorder, which recorded the signals as WAV files at a sample rate of 48,000 samples per second for subsequent signal analysis. The Brüel & Kjaer Type 2250 allowed for real-time approximations of peak and cSEL sound levels while the measurements were being performed.

Airborne sound levels on November 8, 2019 were measured using the Svantek 979 sound level analyzer. All other airborne sound measurements were made using the Svantek 307. Both the instruments meet the requirements for a Type 1 sound level analyzer. This equipment recorded a WAV file at a sample rate of 48,000 samples per second for subsequent signal analysis as well as 1-second logging of unweighted and A-weighted L_{eq}, L_{max}, L_{90}, and L_{95} sound levels. 1-second spectral data were recorded at 1/3 octave resolution.

Photographs of the monitoring equipment are provided Figure 6.1 and Figure 6.2.

Figure 6.1 Hydroacoustic Monitoring Equipment

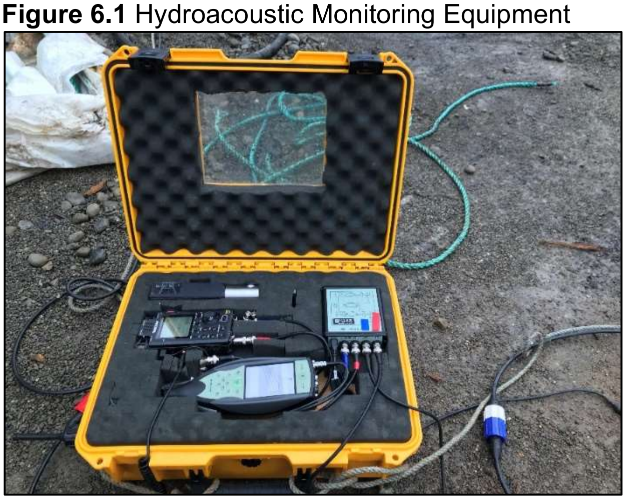


Figure 6.2 Airborne Monitoring Equipment

6.2 Measurement Locations

Two hydrophones were used to measure underwater sound produced by impact pile driving. One near-field hydrophone was located at mid water depth approximately 33 feet (10 meters) from the pile. A far-field hydrophone was positioned at approximately 80% water depth 3H from the pile, where H was the water depth at the pile. Whenever possible, the hydrophones were positioned with a clear acoustic line-of-sight between the hydrophones and pile.

Distances between the pile and microphone ranged between 64 feet and 142 feet. The microphone was located approximately 7-feet above the dock and at least 5-feet from any acoustically reflective surfaces. A direct line-of-sight was maintained between the microphone and piles throughout the measurements.

The distances between the hydrophones and piles were verified using a laser distance measurement device. Water depth was measured at all monitoring locations prior to deploying the hydrophones. Hydrophones were secured to existing portions of Colman Dock and construction platforms.

In addition to water depth measurements, tidal information was obtained from NOAA Station #9447130 and was used to track tidal changes during construction. Table 6.3 presents the depths of the hydrophones, water depth at the measurement locations as well as distances between the hydrophones and piles. Figures illustrating the hydroacoustic measurement positions are presented in Section 7.1 through Section 7.4 of this Report.

Table 6.3 Hydrophone Location Summary, Feet (Meters)

Pile ID	Hydrophone	Depth at Measurement Location	Hydrophone Depth	Distance to Pile
West Side of North Trestle (North Trestle Group B)				
N12.5-NF	Near-Field	30 (9)	16 (5)	30 (9)
	Far-Field	32 (10)	26 (8)	76 (23)
N11-NC.7	Near-Field	41 (13)	35 (11)	30 (9)
	Far-Field	41 (13)	29 (9)	97 (30)
N12-NC.7	Near-Field	43 (13)	35 (11)	30 (9)
	Far-Field	41 (13)	29 (9)	97 (30)
Slip 2 Bridge Seat (battered piles)				
Pile 4	Near-Field	43 (13)	25 (8)	56 (17)
	Far-Field	49 (15)	37 (11)	96 (29)
Pile 3	Near-Field	41 (13)	23 (7)	46 (14)
	Far-Field	47 (14)	35 (11)	89 (27)
Pile 2	Near-Field	38 (12)	20 (6)	36 (11)
	Far-Field	44 (13)	32 (10)	80 (24)
Pile 1	Near-Field	38 (12)	20 (6)	27 (8)
	Far-Field	44 (13)	32 (10)	73 (22)
Wedge Piling				
W1	Near-Field	29 (9)	11 (3)	30 (9)
	Far-Field	37 (11)	25 (8)	92 (28)
East Side of North Trestle (North Trestle Group A)				
E1.1-10 (on-land)	Near-Field	10 (3)	6 (2)	73 (22)
E1.1-8 (on-land)	Near-Field	10 (3)	6 (2)	61 (19)
E3-5	Near-Field	10 (3)	6 (2)	23 (7)

7.0 IMPACT PILE DRIVING ANALYSIS AND RESULTS

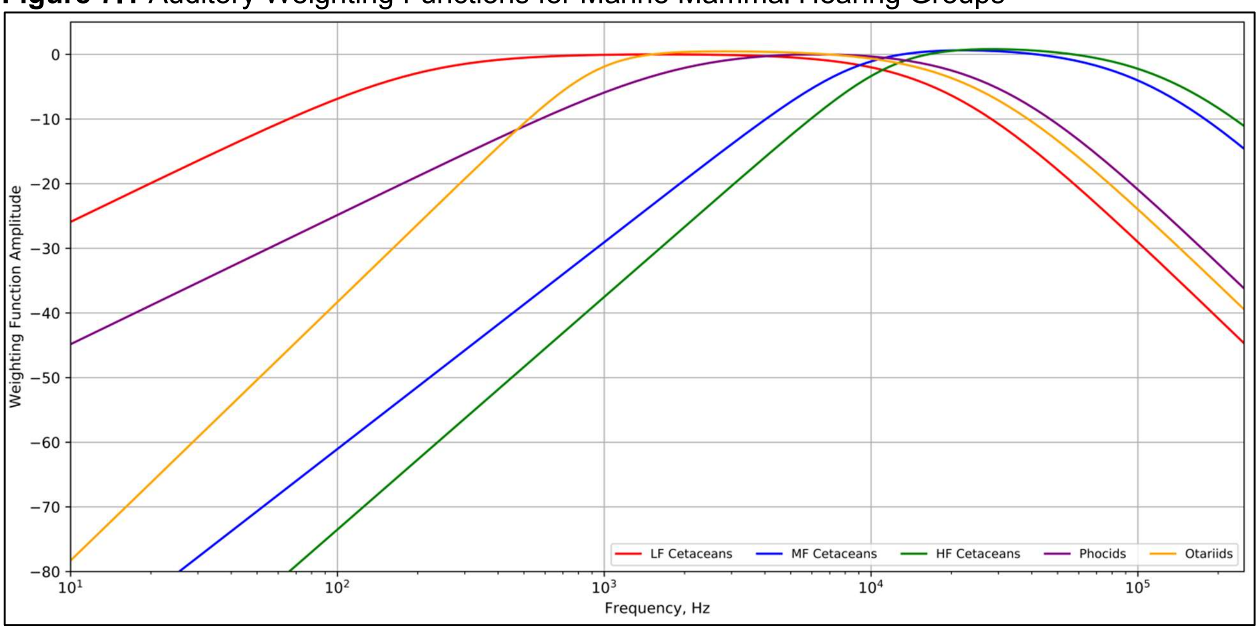
During post-processing the hydroacoustic data were frequency-weighted for each of the marine mammal hearing groups defined in the NOAA technical guidance document titled "Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing" dated April 2018. This Technical Guidance divides marine mammals into five hearing groups, as summarized in Table 7.1.

Table 7.1 Marine Mammal Hearing Groups

Hearing Group	Generalized Hearing Range
Low-frequency (LF) cetaceans (baleen whales)	7 Hz – 35 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whaled, bottlenose whales)	150 Hz – 160 kHz
High-frequency (HF) cetaceans (true porpoise, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger & L. australis*)	275 Hz – 160 kHz
Phocid pinnipeds (PW) (underwater) (true seals)	50 Hz – 86 kHz
Otariid pinnipeds (OW) (underwater) (sea lions and fur seals)	60 Hz -39 kHz

The auditory weighting functions for each of the marine mammal hearing groups are illustrated in Figure 7.1.

Figure 7.1 Auditory Weighting Functions for Marine Mammal Hearing Groups



Underwater noise data collected during impact pile driving were analyzed to determine the range, mean, L_{50} and standard deviation of peak, RMS_{90} and SEL values as well as the cSEL of each pile for each marine mammal functional hearing group as required by the WSDOT Underwater Noise Monitoring Plan. Standard deviation and L_{50} were calculated using decibel values and mean values were calculated using mean sound pressure levels. Periods when pile driving was not occurring under full power were excluded from this analysis. Reported sound levels from the near-field hydrophone have been normalized to 33 feet (10 meters) from the piles using the practical spreading model. For additional information on the practical spreading model please see Section 8.0 of this Report.

The RMS_{90} was established between the 5th percentile and 95th percentile for each recorded pile strike. Figures illustrating the waveforms produced by the pile strikes that generated the absolute highest peak sound pressure level from each pile are provided in the Appendix of this Report. The green portion of these waveforms represents the duration of the strike containing 90% of the acoustical energy.

SEL values were calculated for each pile strike over the duration of the strike containing 90% of the acoustic energy using the following formula:

$$\mathrm{SEL} = \mathrm{RMS(dB)} + 10\log_{10}(\tau)$$

Where τ is the time interval containing 90% of the acoustic energy in each pile strike.

cSEL values were calculated by combining the single strike SEL values for each pile. The resulting cSEL values from each pile driven were combined (logarithmically) to produce daily cSEL values.

Airborne data were analyzed to determine the range and median of 1-second unweighted L_{eq} and L_{max} sound levels as well as A-weighted L_{eq}, L_{max}, L_{90}, and L_{95} sound levels. The 1/3 octave L_{eq} and L_{max} spectral data was also calculated. Periods when pile driving was not occurring are exclude from the analysis.

Details and results of the hydroacoustic and airborne monitoring at the North Trestle, Slip 2 Bridge Seat, and Wedge Piling are discussed in Section 7.1 through Section 7.4.

7.1 West Side of North Trestle (North Trestle Group B) 36-Inch Piles

Acoustic measurements were made during impact pile driving of three 36-inch steel pipe piles at the west side of the North Trestle (North Trestle Group B) on November 8, 2019 and December 4, 2019. During the November measurements the water temperature was approximately 51 degrees Fahrenheit and 53 degrees Fahrenheit during the December measurements. There was no precipitation during the measurements.

During the measurements, both hydrophones were suspended from portions of Colman Dock that had not been demolished. An unobstructed acoustical path between Pile N12-NC.7 and the far-field hydrophone was unable to be established however, both hydrophones maintained an unobstructed path during all other measurements. The microphone was positioned approximately 7-feet above the existing dock with an unobstructed acoustical path to the piles. The locations of the hydrophones, microphone, and piles are shown in Figure 7.2 and Figure 7.3.

Soft start procedures were followed before the drive of Pile N12.5-NF and Pile N11-NC.7. After completion of the soft start for Pile N12.5-NF pile driving commenced for a couple of minutes but was suspended to attached sensors for PDA testing. Pile driving resumed after the attachment of the sensors.

Figure 7.2 November 8, 2019 Pile and Monitoring Locations

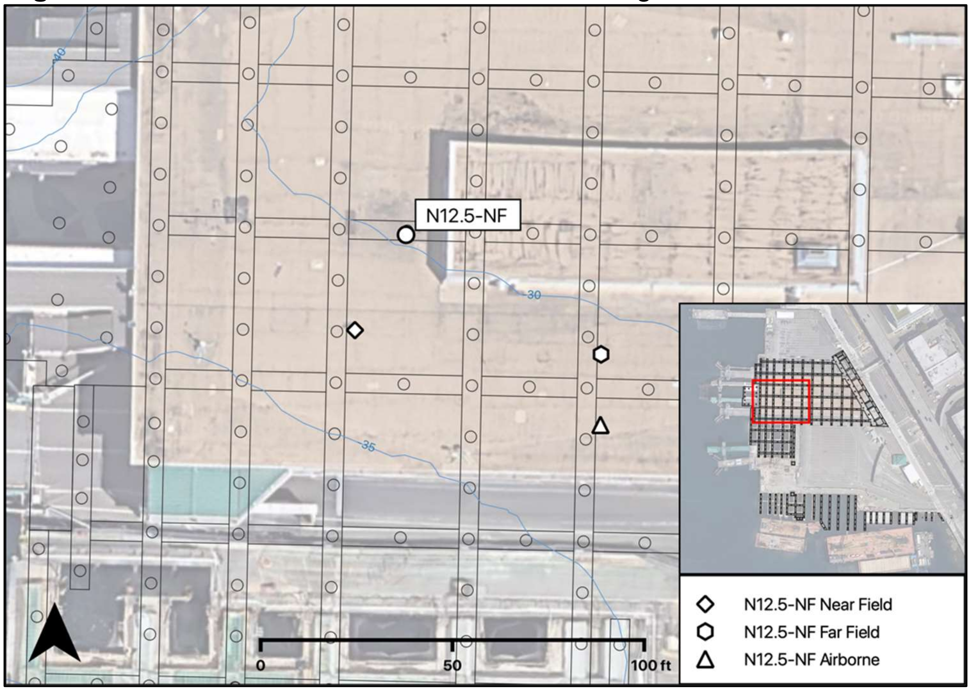
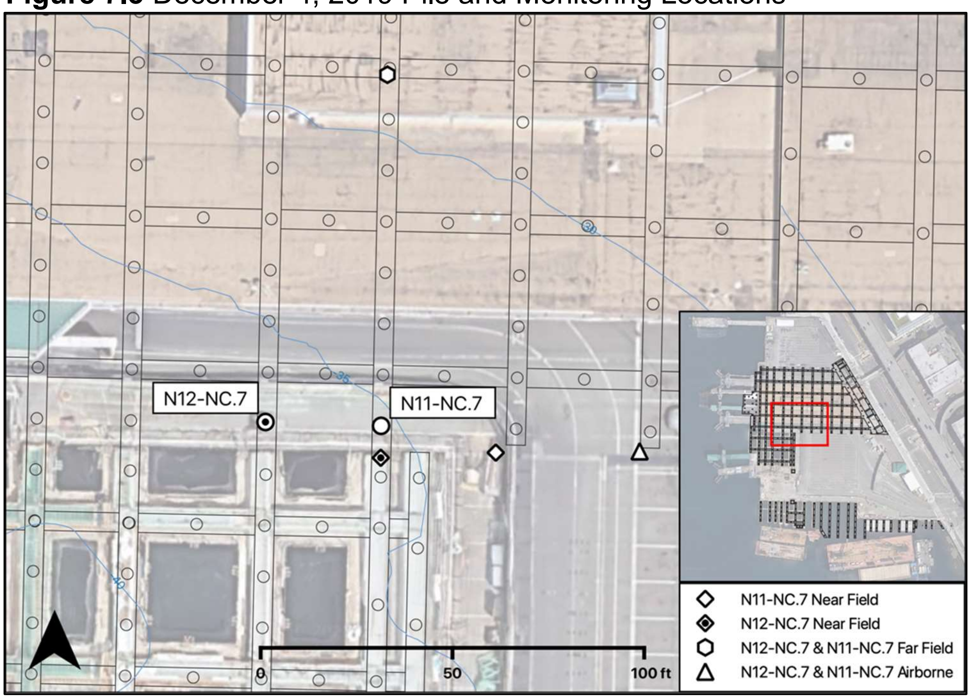


Figure 7.3 December 4, 2019 Pile and Monitoring Locations



Summaries of the airborne and underwater sound levels produced by impact pile driving at the west side of the North Trestle (North Trestle Group B) are shown in Table 7.2 through Table 7.7.

Table 7.2 Pile N12.5-NF Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 30 feet from pile, reported levels normalized to 33 feet)																
Unweighted	173	189	2.6	181	180	162	177	1.8	170	170	154	166	1.4	161	160	188
LF Cetacean						152	167	2.1	160	160	142	155	1.6	150	149	177
MF Cetacean						157	171	1.5	164	164	148	160	1.4	155	154	182
HF Cetacean						158	171	1.5	165	165	149	161	1.4	156	155	183
PW						148	163	1.6	156	156	139	152	1.3	147	146	174
OW						145	160	1.5	154	154	136	148	1.3	145	144	172
Far-Field Hydrophone (76 feet from pile)																
Unweighted	172	184	1.2	181	181	164	178	1.9	175	175	155	166	1.2	164	164	191
LF Cetacean						147	164	1.3	156	155	140	153	1.0	148	148	175
MF Cetacean						160	172	1.8	169	170	150	160	1.2	158	158	186
HF Cetacean						161	173	1.8	170	170	151	160	1.2	159	159	186
PW						150	161	1.4	159	159	141	150	1.1	149	149	176
OW						147	157	1.3	156	156	138	148	1.2	146	146	174

Table 7.3 Pile N12.5-NF Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
94	109	104	104	115	110	91	107	102	100	112	106	79	95	83	75	93	83

1. Sound levels measured 75 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.4 Pile N11-NC.7 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 30 feet from pile, reported levels normalized to 33 feet)																
Unweighted	176	192	2.7	182	181	167	180	2.3	173	172	158	171	2.0	163	163	188
LF Cetacean						155	171	2.3	161	160	147	159	2.0	150	149	174
MF Cetacean						162	175	2.1	167	167	153	165	1.9	157	157	182
HF Cetacean						163	176	2.1	168	167	154	166	1.9	158	157	182
PW						154	167	2.1	159	158	144	156	1.8	149	148	173
OW						151	167	2.1	157	156	141	155	1.8	146	146	171
Far-Field Hydrophone (97 feet from pile)																
Unweighted	167	183	1.7	173	173	160	173	1.3	165	165	151	163	1.3	155	155	180
LF Cetacean						146	160	1.9	152	151	137	151	1.7	143	142	167
MF Cetacean						155	167	1.1	159	159	146	158	1.2	150	150	174
HF Cetacean						155	168	1.1	160	160	146	158	1.2	151	150	175
PW						145	158	1.2	150	150	136	149	1.2	141	141	165
OW						142	156	1.3	148	147	134	147	1.2	139	138	163

Table 7.5 Pile N11-NC.7 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
91	107	105	105	114	111	87	107	105	105	114	111	81	88	83	80	87	82

1. Sound levels measured 94 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.6 Pile N12-NC.7 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 30 feet from pile, reported levels normalized to 33 feet)																
Unweighted	175	186	1.8	181	180	166	174	0.7	171	171	158	164	0.6	162	162	186
LF Cetacean						153	165	1.6	161	161	144	154	1.1	151	150	175
MF Cetacean						161	169	0.7	166	166	152	160	0.6	157	157	181
HF Cetacean						162	169	0.7	167	167	153	161	0.6	158	157	181
PW						152	161	1.0	158	158	143	152	0.8	149	149	173
OW						150	161	1.4	157	157	141	151	1.2	148	147	172
Far-Field Hydrophone (97 feet from pile)																
Unweighted	169	183	1.6	175	174	161	169	1.2	164	164	152	159	1.1	155	155	179
LF Cetacean						149	155	0.9	153	153	140	146	0.7	144	143	167
MF Cetacean						157	166	1.2	160	159	148	157	1.2	150	150	174
HF Cetacean						157	166	1.2	160	160	149	158	1.2	151	151	175
PW						147	156	0.9	151	151	139	148	0.9	142	142	166
OW						145	154	1.0	150	150	136	145	0.9	141	140	164

Table 7.7 Pile N12-NC.7 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
87	106	104	102	112	109	84	105	103	101	111	109	75	86	80	75	85	80

1. Sound levels measured 64 feet from pile. Reported sound levels have been normalized to 50 feet.

The underwater sound levels measured over the duration of each pile drive, the waveform of the of the pile strike which produced the absolute highest peak sound pressure level, and the average underwater frequency spectrum from all pile strikes are provided in the Appendix.

7.2 Slip 2 Bridge Seat 36 Inch Battered Piles

Four 36-inch battered piles were measured the afternoon of January 17, 2020 at the Slip 2 Bridge Seat. During the measurements, the water temperature was 49 degrees Fahrenheit and no precipitation occurred during the measurements.

Both hydrophones were secured to completed sections of Colman Dock and an unobstructed acoustical transmission path was maintained to both hydrophones during all pile driving. The microphone was positioned south of the piles approximately 7 feet above the dock with a direct line-of-sight to the piles. The locations of the piles, microphone, and hydrophones are shown in

Figure 7.4 and a photo of the battered piles is provided in Figure 7.5. Soft start procedures were followed at the start of Pile 1.

Figure 7.4 Slip 2 Bridge Seat Pile and Measurement Locations

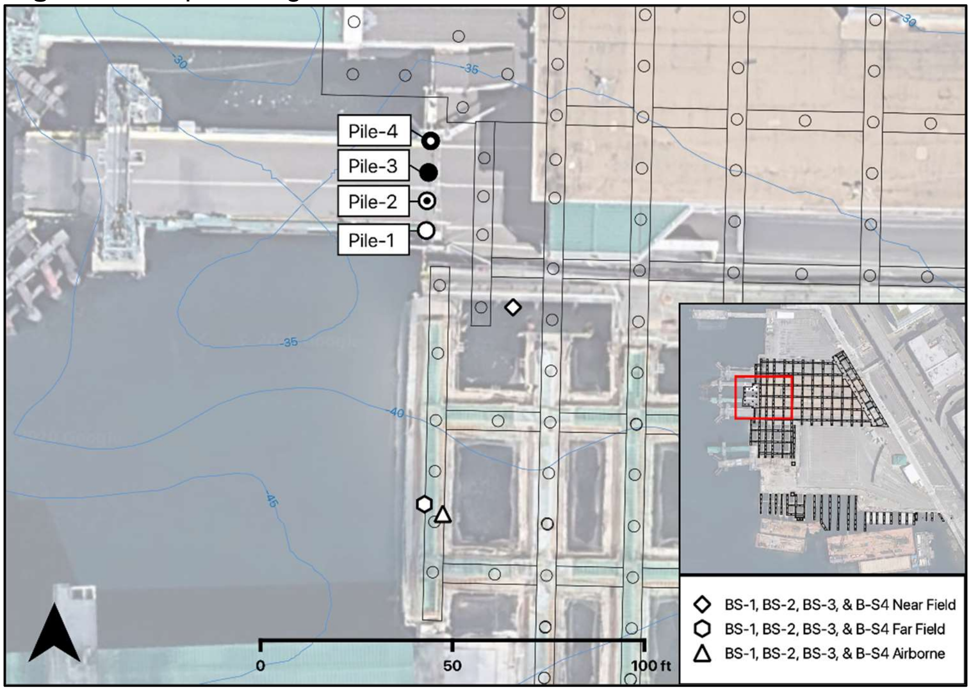
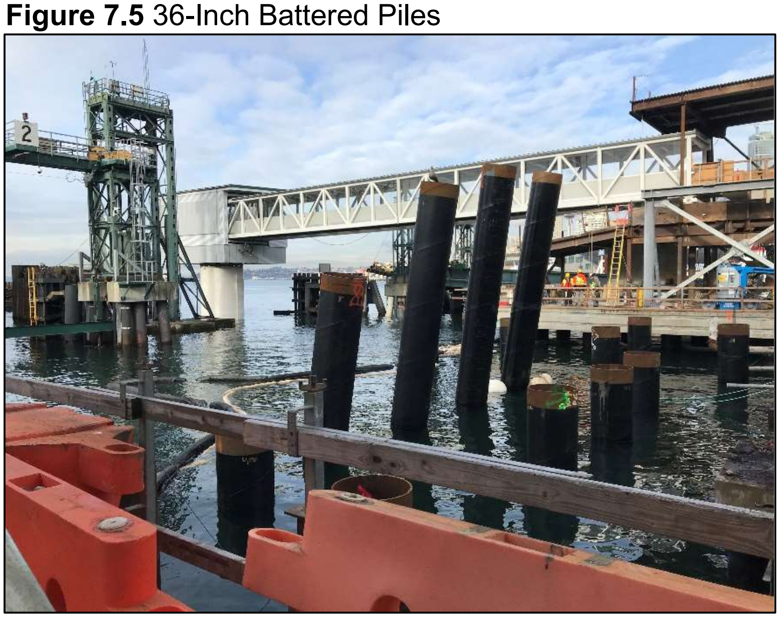


Figure 7.5 36-Inch Battered Piles



Summaries of airborne and underwater sound levels measured during impact pile driving at the Slip 2 Bridge Seat are shown in Table 7.8 through Table 7.15.

Table 7.8 Pile 4 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 56 feet from pile, reported levels normalized to 33 feet)																
Unweighted	187	197	0.9	195	195	174	185	1.2	182	182	162	171	1.0	169	169	196
LF Cetacean						169	178	1.1	176	176	155	165	1.0	163	163	190
MF Cetacean						168	178	1.1	176	175	156	165	0.9	163	163	190
HF Cetacean						169	179	1.2	176	176	156	166	0.9	163	163	191
PW						165	175	0.9	171	171	151	161	0.9	159	159	186
OW						165	175	1.0	171	171	151	162	0.9	159	159	186
Far-Field Hydrophone (96 feet from pile)																
Unweighted	180	189	1.0	186	185	165	176	1.4	172	172	154	164	1.0	161	161	188
LF Cetacean						160	170	1.2	167	167	147	158	1.0	155	155	182
MF Cetacean						159	170	1.3	166	166	148	158	1.0	155	155	182
HF Cetacean						159	170	1.3	166	166	149	159	1.0	156	156	183
PW						154	164	1.1	162	162	143	153	1.0	150	150	177
OW						153	164	1.1	161	161	141	152	1.0	150	150	177

Table 7.9 Pile 4 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
93	108	105	106	113	110	90	106	102	104	110	108	75	88	80	74	85	79

1. Sound levels measured 96 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.10 Pile 3 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 46 feet from pile, reported levels normalized to 33 feet)																
Unweighted	187	200	0.8	196	196	174	185	1.0	182	181	161	170	0.8	168	168	197
LF Cetacean						170	180	0.9	176	176	155	164	0.8	162	162	191
MF Cetacean						168	179	1.0	175	175	155	164	0.8	162	162	191
HF Cetacean						168	180	1.0	176	176	156	164	0.8	163	162	191
PW						165	175	0.9	172	172	151	160	0.8	158	158	187
OW						165	175	0.9	173	173	151	161	0.8	159	159	187
Far-Field Hydrophone (89 feet from pile)																
Unweighted	180	190	1.1	187	187	164	176	1.3	171	171	154	164	0.8	161	160	189
LF Cetacean						160	171	1.1	166	166	148	157	0.9	154	154	183
MF Cetacean						158	169	1.1	166	165	148	158	0.9	154	154	183
HF Cetacean						159	170	1.1	166	166	149	159	0.9	155	155	184
PW						154	166	1.1	162	161	144	153	0.9	150	150	178
OW						155	165	1.0	162	161	143	152	0.9	150	150	178

Table 7.11 Pile 3 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
92	108	105	105	112	110	88	106	102	101	111	108	77	89	81	77	86	80

1. Sound levels measured 89 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.12 Pile 2 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 36 feet from pile, reported levels normalized to 33 feet)																
Unweighted	188	196	0.9	193	193	174	183	1.2	180	180	161	169	0.8	167	167	195
LF Cetacean						169	178	1.0	175	175	154	163	0.8	161	161	189
MF Cetacean						168	177	1.1	174	174	155	163	0.8	161	161	189
HF Cetacean						168	177	1.1	174	174	155	164	0.8	162	162	190
PW						165	174	1.0	170	170	151	159	0.8	157	157	185
OW						166	174	1.2	170	170	151	160	0.9	157	156	185
Far-Field Hydrophone (80 feet from pile)																
Unweighted	182	193	1.6	188	188	164	177	1.2	173	173	154	165	0.9	162	162	190
LF Cetacean						160	173	1.3	168	168	147	159	1.0	156	155	184
MF Cetacean						159	172	1.0	167	167	148	160	0.9	156	156	184
HF Cetacean						159	172	1.0	168	168	149	160	0.9	157	156	185
PW						155	168	1.3	163	163	143	155	1.0	151	151	179
OW						154	169	1.5	163	163	142	155	1.1	151	151	179

Table 7.13 Pile 2 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
90	108	105	104	112	111	87	105	103	101	110	109	77	88	80	75	85	79

1. Sound levels measured 80 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.14 Pile 1 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 27 feet from pile, reported levels normalized to 33 feet)																
Unweighted	180	194	1.8	191	191	168	182	1.6	179	178	156	168	1.2	165	165	190
LF Cetacean						163	177	1.5	174	173	149	162	1.3	159	159	184
MF Cetacean						163	176	1.5	172	172	150	162	1.2	159	159	184
HF Cetacean						163	176	1.5	173	173	151	163	1.2	160	160	185
PW						157	173	1.7	169	169	145	158	1.4	155	155	180
OW						158	174	2.0	169	169	144	159	1.8	155	155	180
Far-Field Hydrophone (73 feet from pile)																
Unweighted	181	192	1.1	189	189	165	175	1.0	173	173	154	163	0.8	162	162	187
LF Cetacean						160	170	1.0	168	168	147	157	0.9	155	155	181
MF Cetacean						159	169	1.1	167	167	148	157	0.8	156	156	181
HF Cetacean						159	170	1.1	168	168	149	158	0.8	156	156	182
PW						154	165	1.0	164	164	143	153	0.9	151	151	177
OW						153	166	1.0	164	164	142	153	1.0	151	151	177

Table 7.15 Pile 1 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
91	107	105	104	112	110	88	105	103	101	110	108	78	87	80	77	85	79

1. Sound levels measured 73 feet from pile. Reported sound levels have been normalized to 50 feet.

The underwater sound levels measured over the duration of each pile drive, the waveform of the of the pile strike which produced the absolute highest peak sound pressure level, and the average underwater frequency spectrum from all pile strikes are provided in the Appendix.

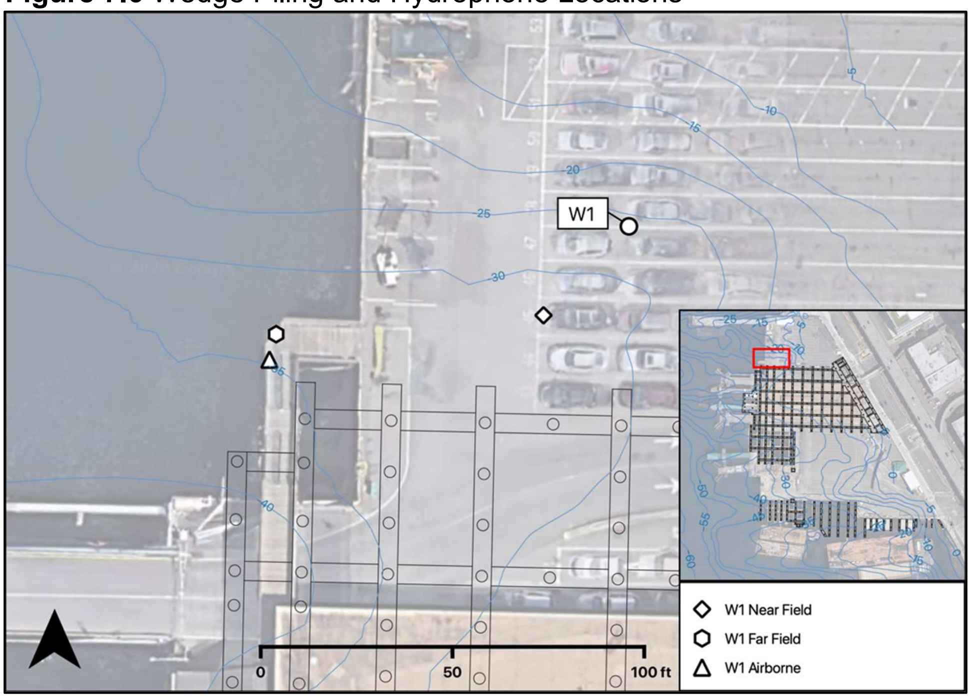
7.3 Wedge Piling

Acoustic measurements were made during impact pile driving of one 24-inch steel pipe pile during the morning of February 26, 2020. During the measurements, the water temperature was approximately 48 degrees Fahrenheit and there was no precipitation.

Both hydrophones were secured to completed sections of Colman Dock and an unobstructed acoustical transmission path was maintained to both hydrophones during the drive. The microphone was 7 feet above the dock and was approximately 91 feet from the pile. The locations of the pile, microphone, and hydrophones are shown in Figure 7.6.

Soft start procedures were followed at the beginning of the drive. However, the APE D62 diesel impact hammer was unstable on top of the pile. The hammer was also misfiring, and the piston height varied through the pile drive which resulted in variable sound levels.

Figure 7.6 Wedge Piling and Hydrophone Locations



Summaries of the airborne and underwater sound levels generated by impact pile driving of the 24-inch pile are shown in Table 7.16 and Table 7.17.

Table 7.16 Pile W1 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 30 feet from pile, reported levels normalized to 33 feet)																
Unweighted	175	189	2.1	180	179	162	174	2.4	168	168	152	162	2.0	157	156	180
LF Cetacean						156	168	2.2	161	160	144	154	1.9	148	147	171
MF Cetacean						157	168	2.1	163	162	147	156	1.9	151	150	174
HF Cetacean						157	169	2.2	163	163	147	156	2.0	151	151	174
PW						154	167	2.4	159	158	142	153	2.1	146	145	169
OW						153	167	2.8	159	158	141	154	2.4	146	144	169
Far-Field Hydrophone (92 feet from pile)																
Unweighted	167	184	2.5	173	172	158	168	1.8	163	162	149	158	1.8	153	153	176
LF Cetacean						146	159	2.6	153	151	137	147	2.1	142	141	165
MF Cetacean						153	162	1.8	157	156	144	152	1.7	147	147	170
HF Cetacean						153	162	1.8	157	157	144	153	1.7	148	148	171
PW						144	158	3.0	150	148	135	148	2.5	141	139	164
OW						142	160	3.9	150	146	133	148	3.1	139	137	162

Table 7.17 Pile W1 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
93	106	102	104	112	108	89	103	100	100	110	106	79	90	81	77	89	80

1. Sound levels measured 91 feet from pile. Reported sound levels have been normalized to 50 feet.

The underwater sound levels measured over the duration of the pile drive, the waveform of the of the pile strike which produced the absolute highest peak sound pressure level, and the average underwater frequency spectrum from all pile strikes are provided in the Appendix.

7.4 East Side of North Trestle (North Trestle Group A) 36-Inch Piles

Measurements were made of impact pile driving of three 36-inch piles at the east side of the North Trestle (North Trestle Group A) during the afternoon of February 26, 2020. Water temperature during the measurements was approximately 48 degrees Fahrenheit and there was no precipitation. Due to tidal conditions Pile E1.1-10 and Pile E1.1-8 were driven above the waterline.

Only one hydrophone was used to monitor underwater sound levels because two of the piles were driven above the waterline and the far-field hydrophone would have been positioned closer than 33 feet (10 meters) from the pile due to the shallow water depth at the pile. The hydrophone was suspended from a temporary work trestle and maintained a direct path of acoustical transmission to the in-water pile and no piles were located between the hydrophone and the two piles driven above the waterline. The microphone was located south of the piles and was approximately 7-feet above the dock. The locations of the piles, microphone, and hydrophone are shown in Figure 7.7 and a photograph of Pile E1.1-10 being driven above the waterline is provided in Figure 7.8.

Soft start procedures were followed at the start of Pile E1.1-10 even though the pile was located above the waterline.

Figure 7.7 North Trestle (Group A) Pile and Hydrophone

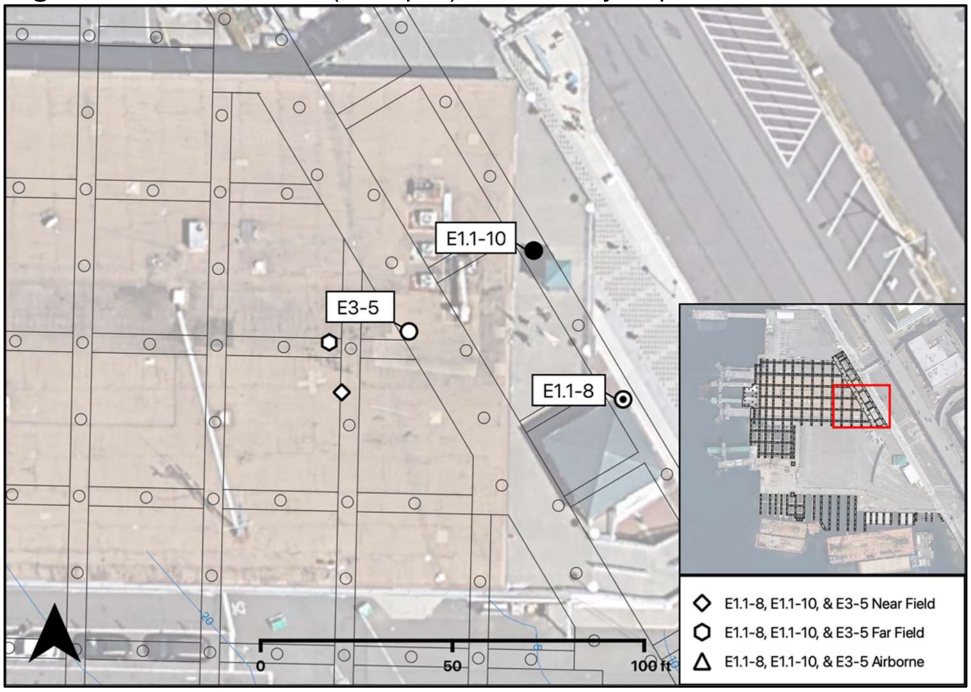
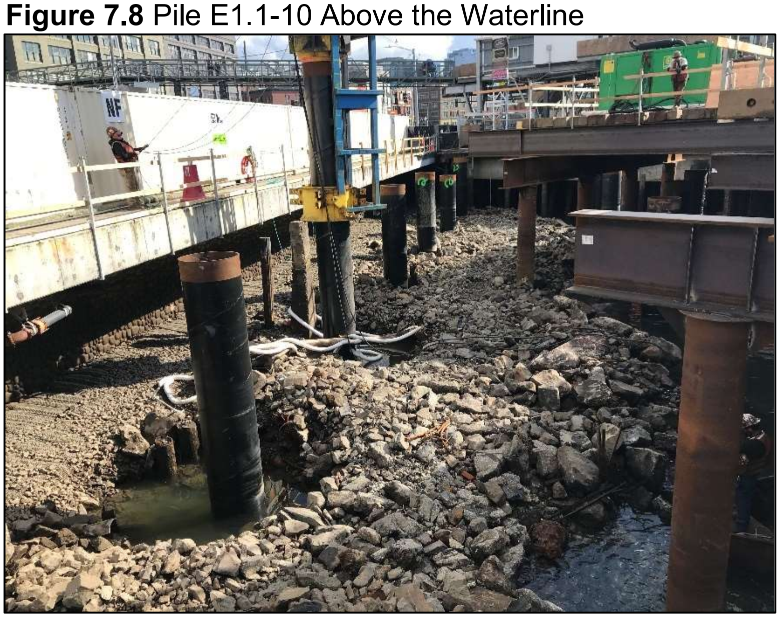


Figure 7.8 Pile E1.1-10 Above the Waterline



Summaries of the airborne and underwater sound levels generated by impact pile driving of the 36-inch piles are shown in Table 7.18 through Table 7.23.

Table 7.18 Pile E1.1-10 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 73 feet from pile, reported levels normalized to 33 feet)																
Unweighted	161	166	0.9	165	165	139	160	1.3	158	159	130	148	1.1	146	146	175
LF Cetacean						133	139	0.8	137	138	124	131	0.7	129	129	158
MF Cetacean						140	154	2.0	152	152	130	141	0.9	140	140	169
HF Cetacean						140	155	2.1	152	153	130	142	0.9	141	141	170
PW						135	142	1.2	140	140	127	132	0.8	131	131	160
OW						133	139	0.9	137	137	125	130	0.7	128	128	158

Table 7.19 Pile E1.1-10 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
90	108	105	10	114	110	86	104	101	100	111	107	74	92	82	74	91	81

1. Sound levels measured 92 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.20 Pile E1.1-8 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS_{90}					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Near-Field Hydrophone (measured 61 feet from pile, reported levels normalized to 33 feet)																
Unweighted	158	164	0.8	162	162	149	157	1.5	155	155	141	145	0.8	144	144	170
LF Cetacean						132	137	0.6	135	135	125	129	0.6	128	128	153
MF Cetacean						143	149	0.8	146	146	135	139	0.7	138	138	164
HF Cetacean						144	150	0.8	147	147	136	140	0.7	139	139	165
PW						134	139	0.7	137	137	126	130	0.6	129	129	155
OW						132	136	0.6	135	135	124	128	0.5	127	127	152

Table 7.21 Pile E1.1-8 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
L_{eq}			L_{max}			L_{eq}			L_{max}			L_{90}			L_{95}		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
95	110	106	108	117	112	90	105	102	103	111	107	80	90	83	79	88	82

1. Sound levels measured 139 feet from pile. Reported sound levels have been normalized to 50 feet.

Table 7.22 Pile E3-5 Underwater Sound Levels, dB re: 1 μPa

Frequency Range	Peak					RMS90					SEL					cSEL
	Min	Max	SD	Mean	L50	Min	Max	SD	Mean	L50	Min	Max	SD	Mean	L50	
Near-Field Hydrophone (measured 23 feet from pile, reported levels normalized to 33 feet)																
Unweighted	189	201	2.1	196	195	180	186	1.1	183	183	165	170	1.0	168	168	197
LF Cetacean						175	181	1.2	178	178	159	165	1.0	163	163	191
MF Cetacean						174	181	1.1	178	178	159	165	1.0	162	162	191
HF Cetacean						175	181	1.1	178	178	159	165	1.0	163	163	191
PW						173	180	1.3	176	176	157	163	1.1	161	161	189
OW						174	181	1.4	177	177	158	164	1.2	162	162	190

Table 7.23 Pile E3-5 Airborne Sound Levels, dB re: 20 μPa[1]

Unweighted						A-Weighted											
Leq			Lmax			Leq			Lmax			L90			L95		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
91	108	103	101	114	109	86	107	101	99	114	107	79	93	82	78	91	81

1. Sound levels measured 142 feet from pile. Reported sound levels have been normalized to 50 feet.

The underwater sound levels measured over the duration of each pile drive, the waveform of the of the pile strike which produced the absolute highest peak sound pressure level, and the average underwater frequency spectrum from all pile strikes are provided in the Appendix.

8.0 DISTANCE TO MARINE MAMMAL DISTURBANCE AND INJURY THRESHOLDS

Data collected during impact pile driving was used to estimate the distance required for underwater sound levels to reach the disturbance and injury thresholds for fish and marine mammals.

The distances were calculated using the “practical spreading model” currently used by NOAA. The practical spreading formula is provided below.

$$\mathrm{SPL}_{D2} = \mathrm{SPL}_{D1} + \beta * \log_{10}\left(\frac{D_1}{D_2}\right)$$

Where SPL_{D1} is the sound pressure measured at a distance, D_1 and SPL_{D2} is the estimated sound pressure at a distance, D_2. β is the attenuation factor resulting from acoustic spreading over distance. The California Department of Transportation (Caltrans) reported in the “Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish” dated November, 2015, that β can range between 5 and 30 depending upon site specific conditions such as water depth, pile type, pile length and the substrate the pile is driven into. Currently NOAA uses the practical spreading model with β equaling 15, which results in a 4.5 dB reduction in underwater sound levels for each doubling of distance.

The distances required for underwater noise to reach the disturbance and injury thresholds for fish and marine mammals are estimated by solving the practical spreading formula for D_2 resulting in the following:

$$D_2 = D_1 * 10\left(\frac{\mathrm{SPL}_{D1} - \mathrm{SP}_{D2}}{15}\right)$$

To estimate the distances required for underwater noise to reach the disturbance and injury thresholds sound levels measured by the far-field hydrophone were normalized to their average measurement distance of 80 feet (24 meters) to allow for comparison of measured sound levels. After calculating the far-field sound levels at 80 feet (24 meters), the highest median peak, RMS_{90} and highest daily cSEL values were used to calculate the distances required for sound to reach marine mammal thresholds. The far-field hydrophone provides a more accurate estimate of sound levels at greater distances, as described in the National Marine Fisheries Service Guidance Document titled “Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals”, dated January 31, 2012.

8.1 Marine Mammal Threshold Distances

The results of the acoustic monitoring and analysis were used to estimate the distances required for underwater sound levels to reach the marine mammal injury (Level A) and disturbance (Level B) thresholds.

In April 2018, NOAA issued updated technical guidance for determining the effects of underwater sound on marine mammals titled “Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing”. The Technical Guidance utilizes dual threshold criteria for injury from impulsive sounds, such as impact pile driving. These criteria are peak sound pressure and cSEL values accumulated over a 24-hour period. The peak sound pressure criteria are unweighted and the cSEL values are frequency-weighted for each marine mammal hearing group. Injury thresholds from impulsive sounds are in Table 8.1.

Table 8.1 Injury Thresholds, dB re: 1 μPa

Hearing Group	Impulsive	
	Peak (unweighted)	cSEL (weighted)
Low-frequency (LF) cetaceans	219	183
Mid-frequency (MF) cetaceans	230	185
High-frequency (HF) cetaceans	202	155
Phocid pinnipeds (PW) (underwater)	218	185
Otariid pinnipeds (OW) (underwater)	232	203

Source: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, April 2018

Marine mammal disturbance thresholds (Level B) from underwater sound are based on RMS sound levels from previous guidance and are shown in Table 8.2.

Table 8.2 Disturbance Thresholds (RMS), dB re: 1 μPa

Marine Mammal	Impact Pile Driving Disturbance Threshold
Cetaceans	160
Pinnipeds	

Source: National Marine Fisheries Service

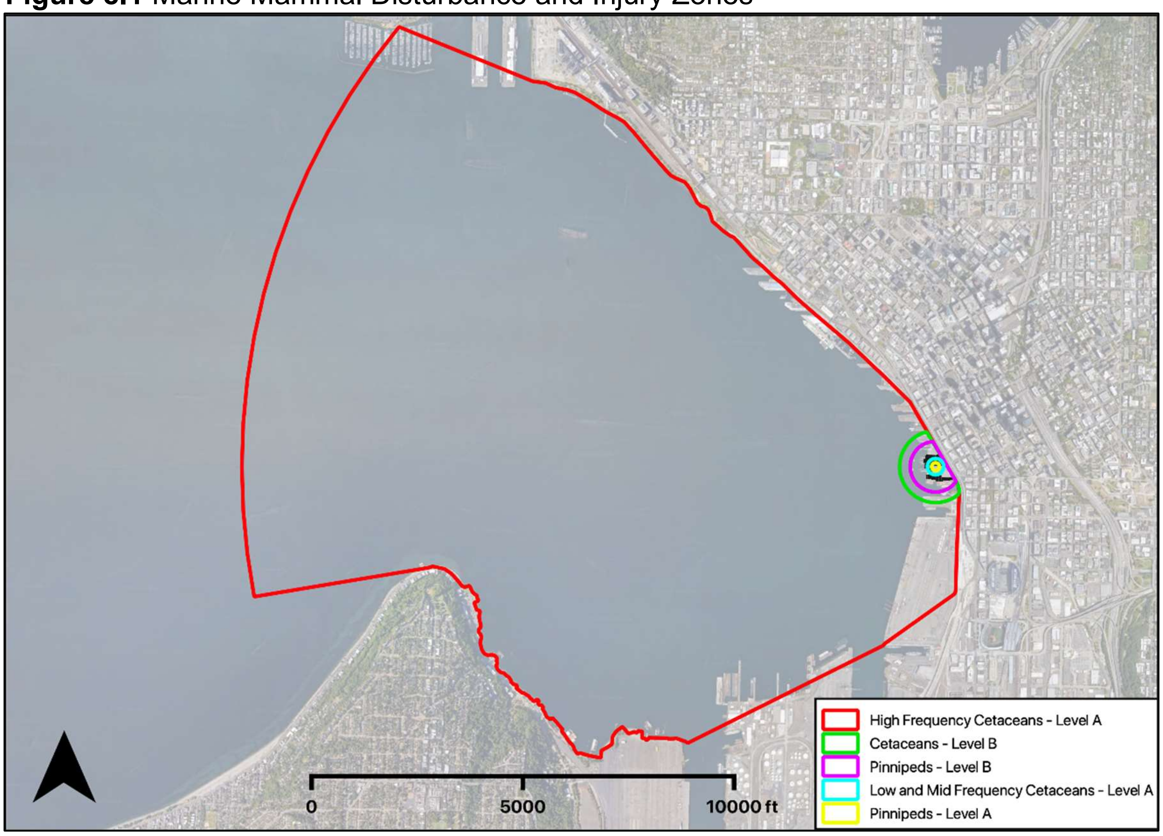
The practical spreading model, the highest 24-hour cSEL values, and the loudest average peak, and RMS_{90} sound levels recorded during pile driving were used to calculate the distances necessary for underwater sound to reach Level A and Level B thresholds. The resulting distances for impact pile driving distances are shown in Table 8.3.

Table 8.3 Distances to Marine Mammal Thresholds from Impact Pile Driving, Feet (Meters)

Hearing Group	Measured Sound Level			Marine Mammal Threshold			Distance to Threshold		
				Level A		Level B	Level A		Level B
	Peak	cSEL	RMS_{90}	Peak	cSEL	RMS_{90}	Peak	cSEL	RMS_{90}
LF Cetaceans	193	189	175	219	183	160	1.6 (0.5)	194 (59)	852 (260)
MF Cetaceans	193	189	175	230	185		0.3 (0.1)	150 (46)	807 (246)
HF Cetaceans	193	190	175	202	155		21.3 (6.5)	16,442 (5,011)	852 (260)
Pinnipeds (Phocids)	193	186	173	218	185		1.8 (0.5)	92 (28)	575 (175)
Pinnipeds (Otariids)	193	187	173	232	203		0.2 (0.1)	6 (1.8)	629 (192)

As shown in Table 8.3, the estimated distances required for sound produced by impact pile driving to reach the 160 dB marine mammal disturbance threshold is up to 852 feet (260 meters) from the pile. Approximately 16,442 feet (5,011 meters) may be required for sound to dissipate to below the Level A injury thresholds for high-frequency cetaceans, 194 feet (59 meters) for other cetaceans, and 92 feet (28 meters) for pinnipeds. Figure 8.1 illustrates the areas where underwater sound levels are expected to exceed the Level A and Level B thresholds for marine mammals. Descriptions of observed marine mammal behavior can be found in the marine mammal monitoring report.

Figure 8.1 Marine Mammal Disturbance and Injury Zones



8.2 Fish Threshold Distances

In 2008. The Fisheries Hydroacoustic Working Group, the Federal Highway Administration and Federal Agencies, including the National Marine Fisheries Service (NMFS), agreed upon dual sound level threshold criteria for the onset of injury to fish. These thresholds include peak sound pressure levels and cSEL levels for fish weighing more than 2 grams and fish weighing less than 2 grams. These thresholds as well as the threshold for "effective quiet" are shown in Table 8.4.

Table 8.4 Threshold Levels for Fish, dB re: 1 μPa

Effect	Metric	Fish Mass	Threshold
Physical Injury	Peak	N/A	206
	Daily cSEL	< 2 grams	183
		≥ 2 grams	187
Effective Quiet	Single Strike SEL	N/A	150

The distances for underwater sound levels to reach the threshold values listed in Table 8.4 were calculated using the practical spreading model and the highest mean peak and single strike SEL unweighted sound levels as well as the highest daily cSEL level measured by the far-field hydrophone. The resulting distances are provided in Table 8.5.

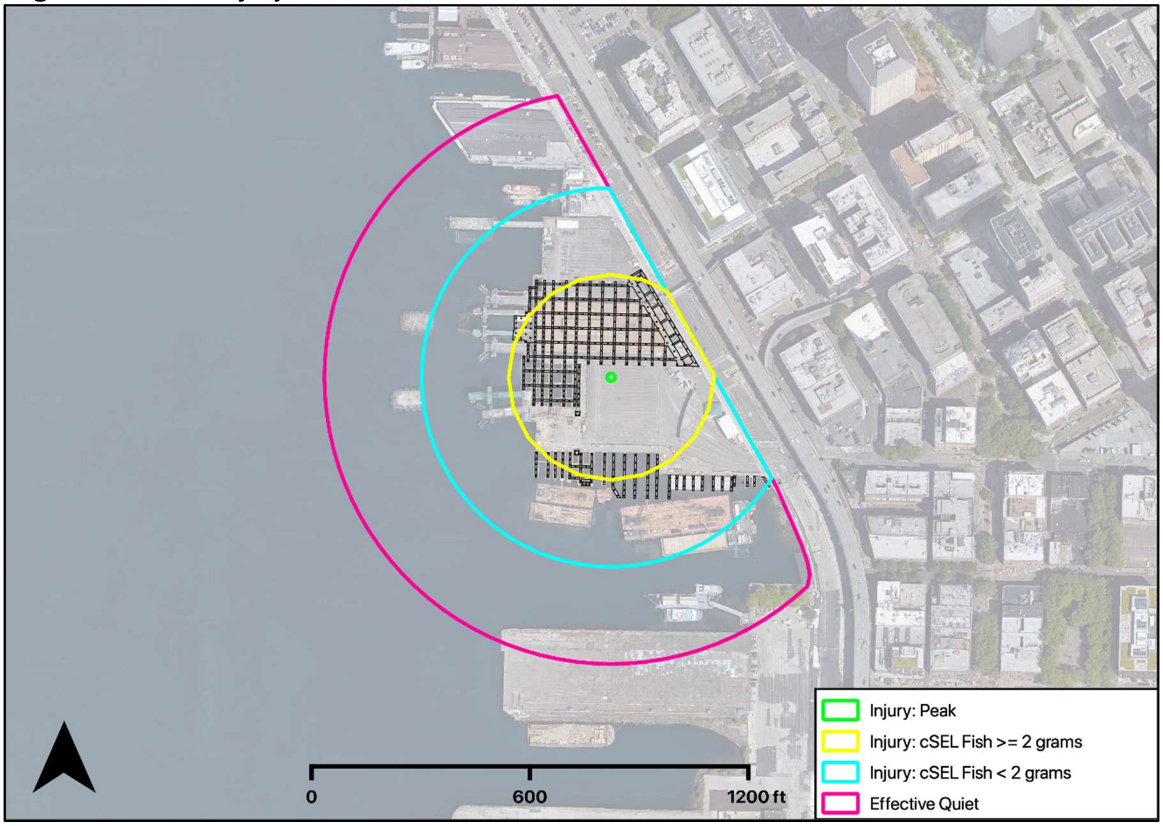
Table 8.5 Distances to Fish Thresholds, Feet (Meters)

Effect	Metric	Measured Sound Level	Fish Mass	Threshold	Distance
Physical Injury	Peak	193[1]	N/A	206	**12 (3.7)**
	Daily cSEL	195[2]	< 2 grams	183	**522 (159)**
			≥ 2 grams	187	**282 (86)**
Effective Quiet	Single Strike SEL	165[1]	N/A	150	**789 (241)**

1. The highest mean peak and singe strike SEL sound levels were measured during impact pile driving of Pile E3-5.
2. The highest daily unweighted cSEL sound level was measured by the far-field hydrophone on January 17, 2020.

Figure 8.2 illustrates the areas where underwater sound levels are expected to exceed the injury and effective quiet thresholds for fish.

Figure 8.2 Fish Injury and Effective Quiet Zones



9.0 PREDICTED AIRBORNE SOUND LEVELS AT NEARBY PROPERTIES

Airborne sound levels measured during Season 3 were used to predict sound levels at nearby residential properties.

Sound levels were predicted using a 3-D computer noise model. The computer noise model uses the acoustic modeling software Cadna/A. Cadna/A utilizes the CADNA (Control of Accuracy and Debugging for Numerical Applications) computation engine developed by the Pierre et Marie Curie University in Paris. The model accounts for the effects of distance, topography, and surface reflections on sound levels produced by impact pile driving.

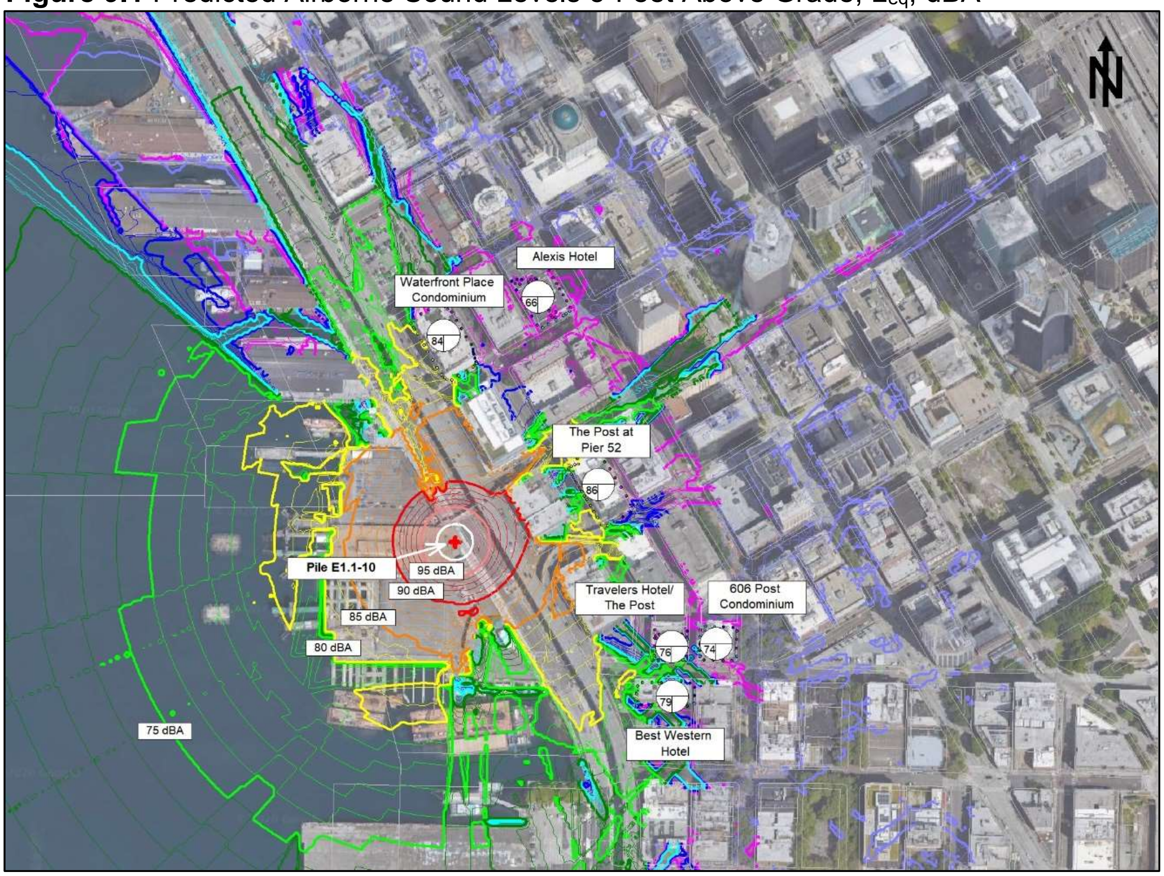
The computer noise model was generated based on pile locations determined from project drawings and sound levels measured during Season 3. Elevation contours and locations and heights of nearby buildings were based on Geographic Information System (GIS) data downloaded from the Seattle Department of Construction and Inspections website.

Predicted sound levels at nearby residential properties are shown in Table 9.1. Sound contours predicted 5-feet (1.5 meters) above grade from the pile which produced the loudest predicted sound levels at nearby properties are shown in Figure 9.1.

Table 9.1 Predicted Airborne Sound Levels at Nearby Residential Properties

Property	Predicted 1-Second L_{eq} at Nearby Residential Use Properties, dBA										
	N12.5-NF	N12-NC.7	N11-NC.7	Pile 4	Pile 3	Pile 2	Pile 1	W1	E3-5	E1.1-10	E1.1-8
The Post at Pier 52	77	78	81	77	77	78	77	77	84	86	82
Waterfront Place	77	78	80	77	77	78	76	79	82	84	80
Alexis Hotel	71	72	72	71	71	72	71	72	65	66	63
Best Western Plus Pioneer Square Hotel	72	74	76	73	73	74	73	71	77	78	76
606 Post Condominium	69	70	72	69	69	70	69	67	73	74	72
Travelers Hotel the Post Condominium	59	68	70	65	66	68	67	68	74	75	73

Figure 9.1 Predicted Airborne Sound Levels 5-Feet Above Grade, L_{eq}, dBA



10.0 REFERENCES

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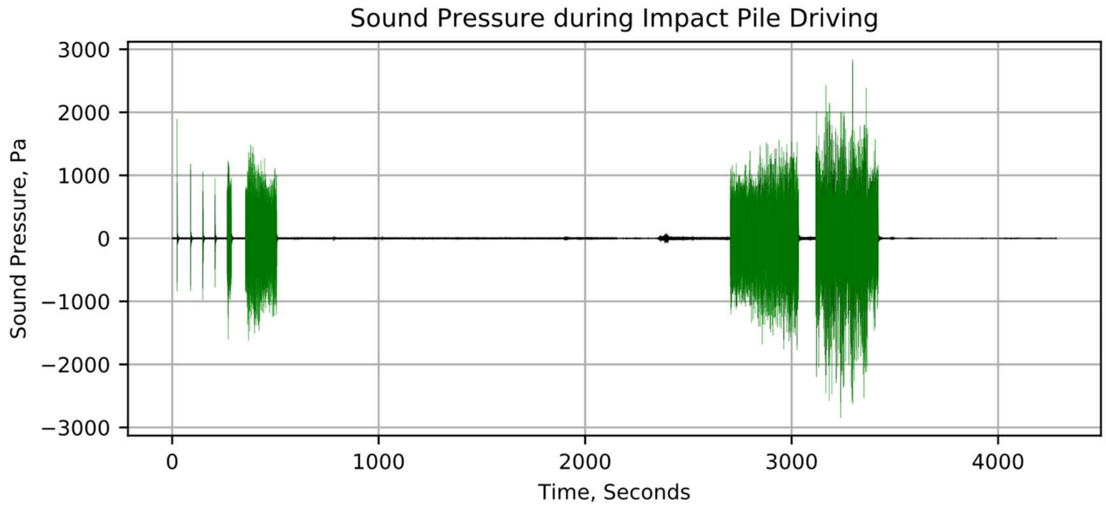
APPENDIX

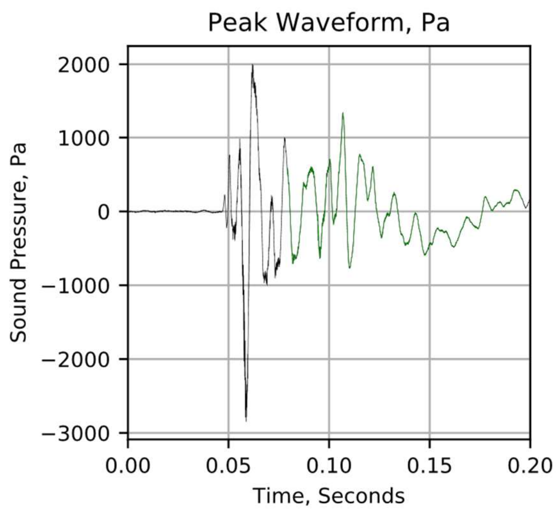
Table of Contents

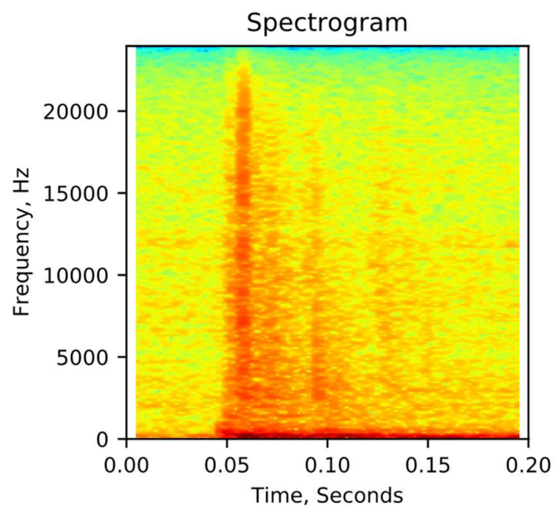
1.0 WEST SIDE OF NORTH TRESTLE (GROUP B) 36-INCH STEEL PIPE PILES

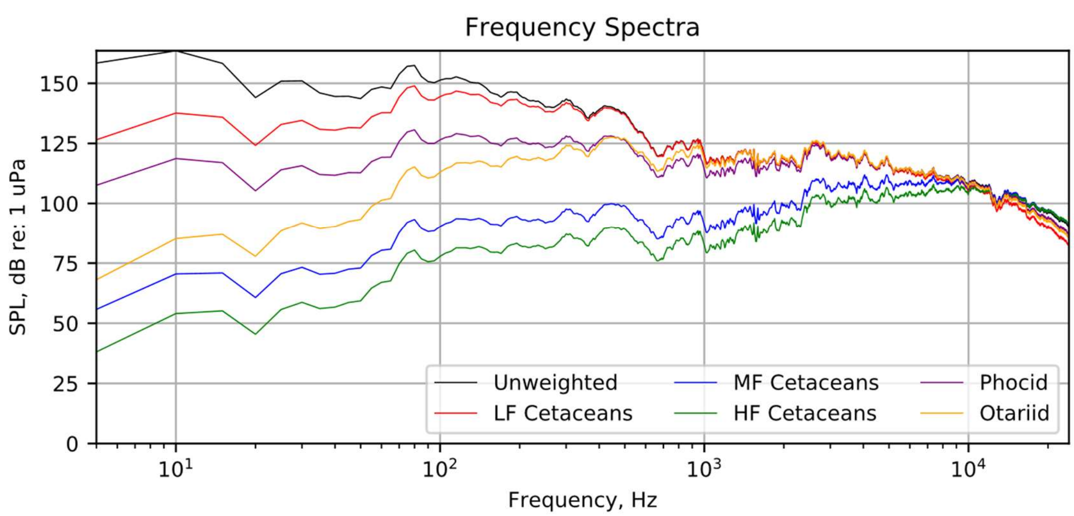
PILE – N12.5-NF

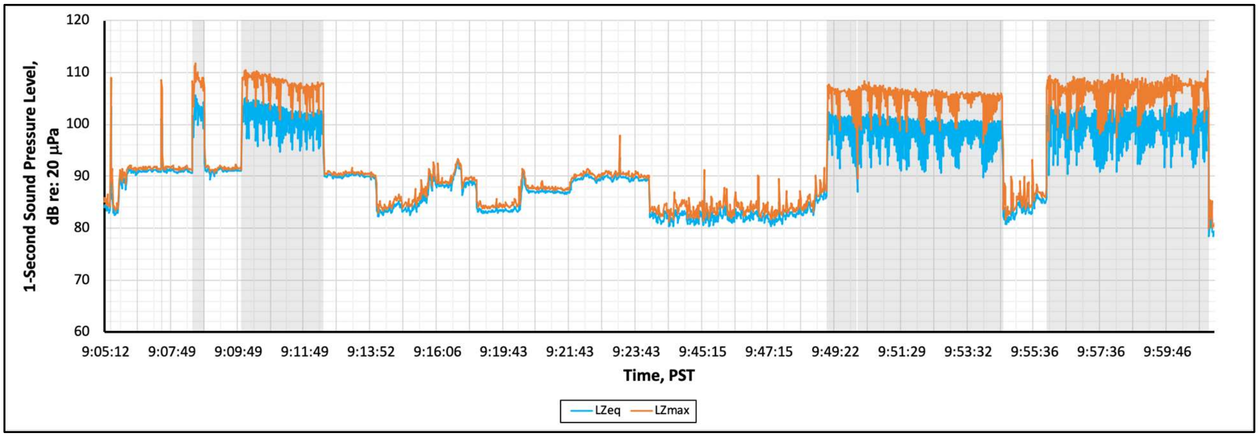
November 8, 2019







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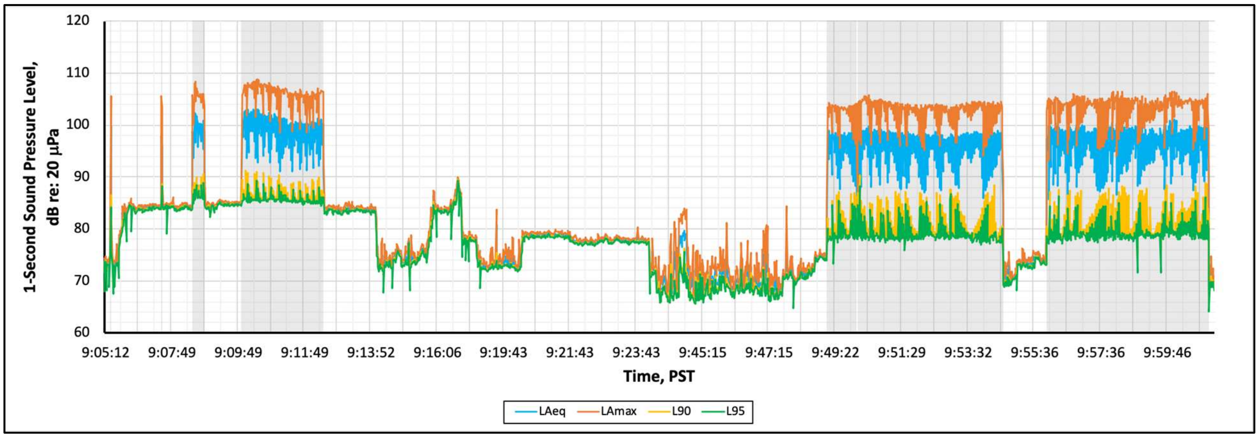
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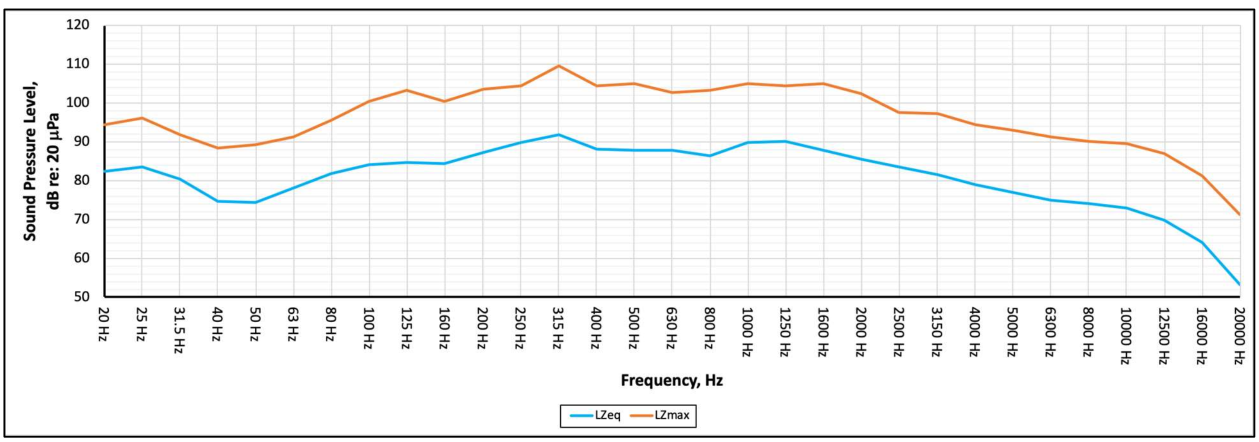
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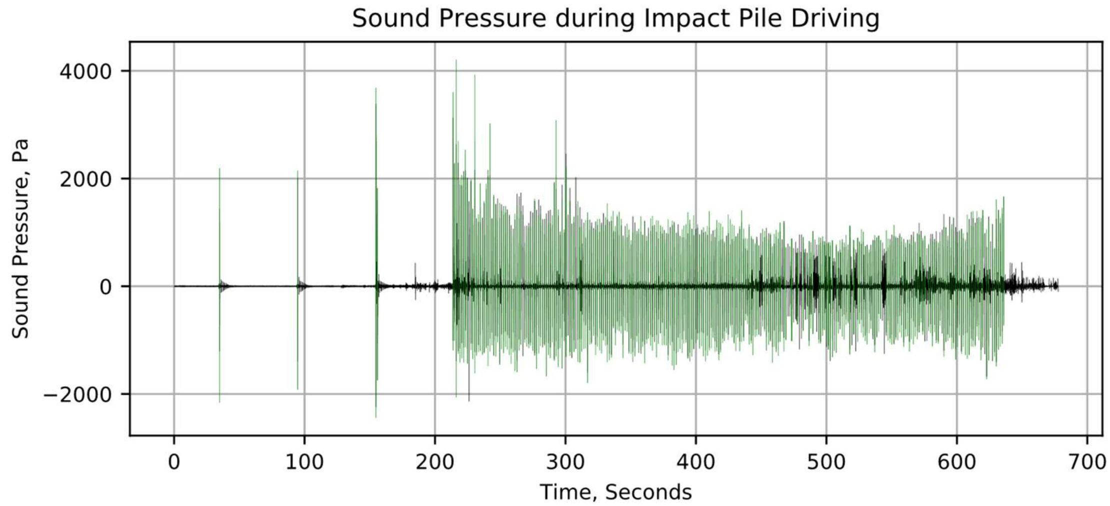
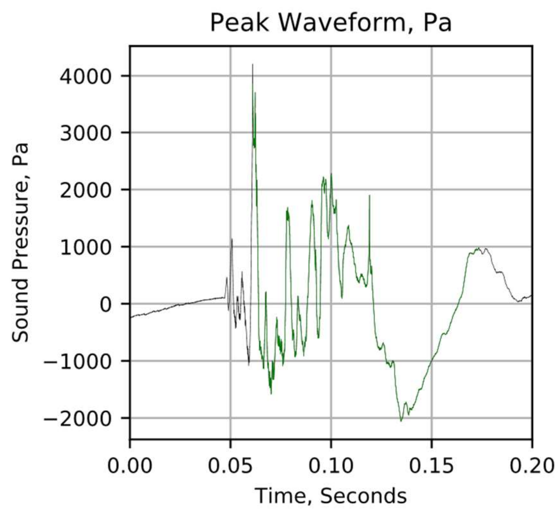
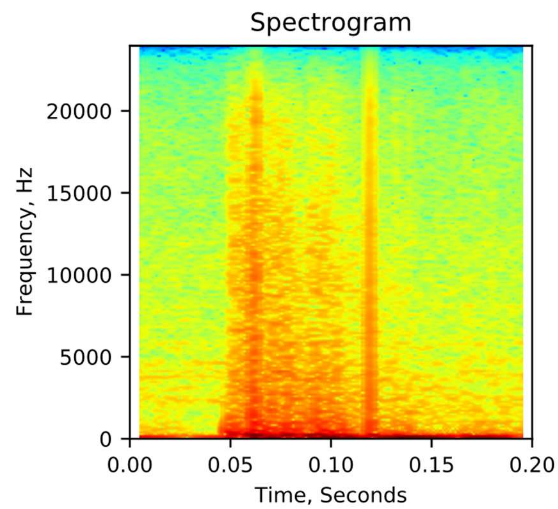
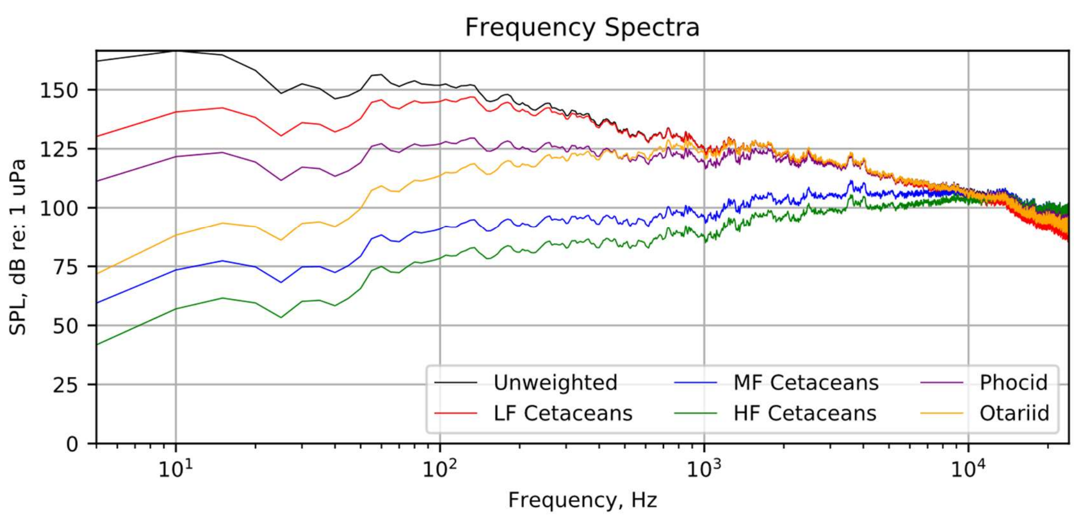
PILE – N11-NC.7

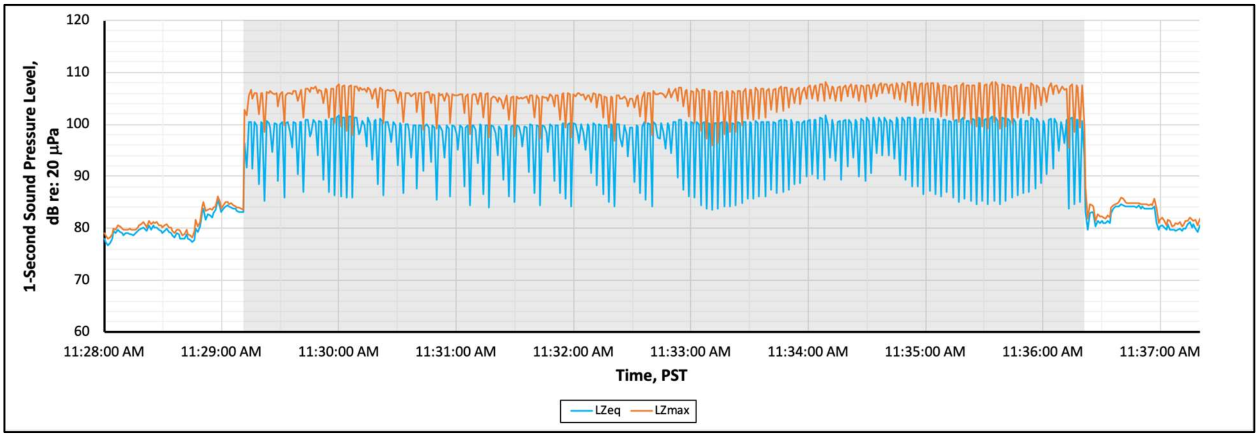
December 4, 2019







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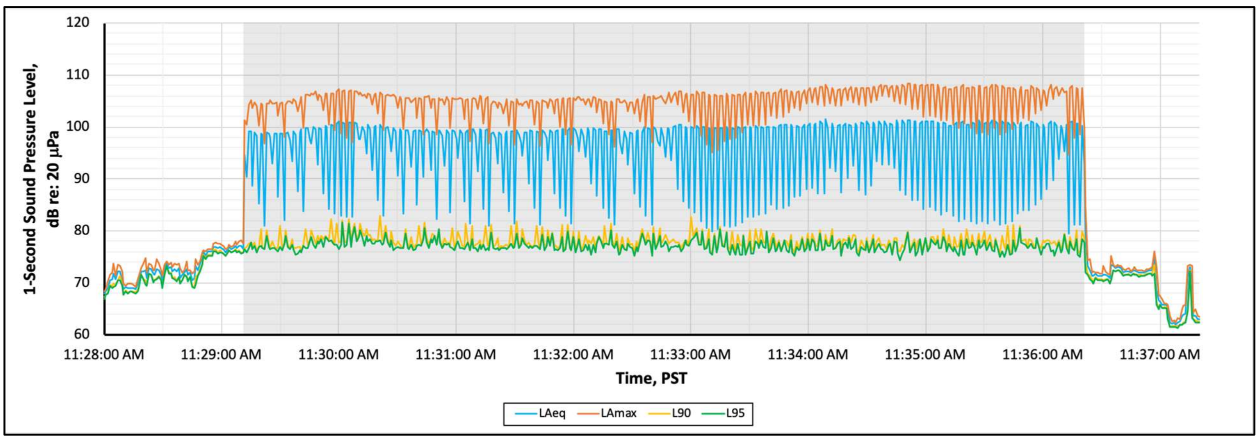
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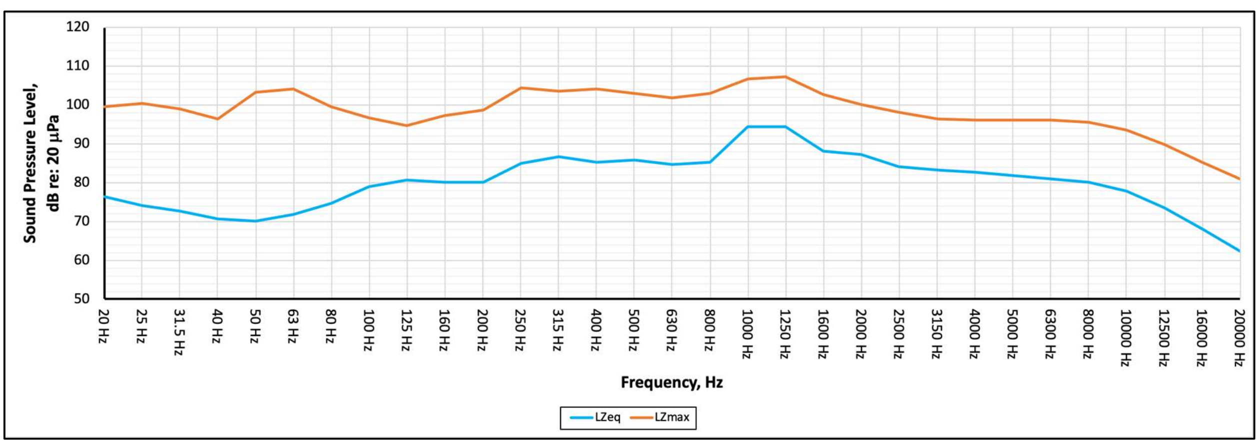
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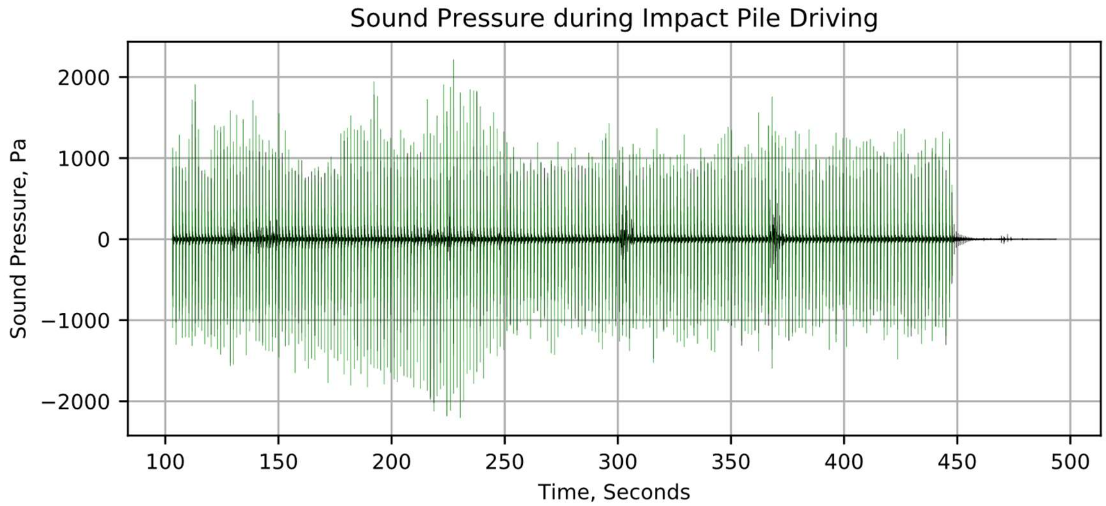

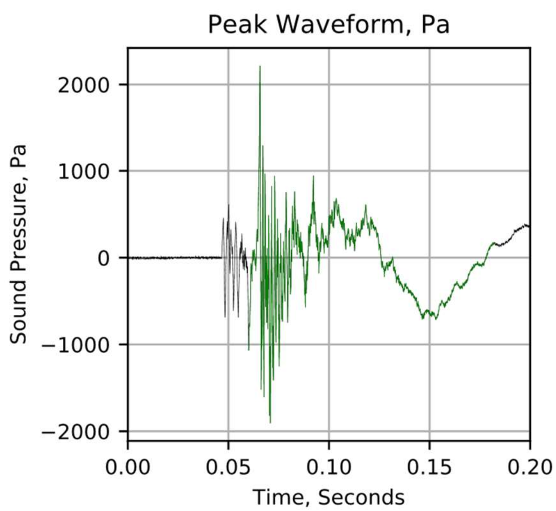

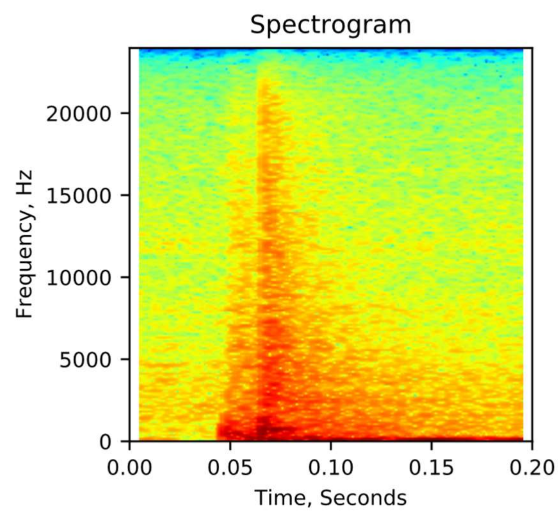

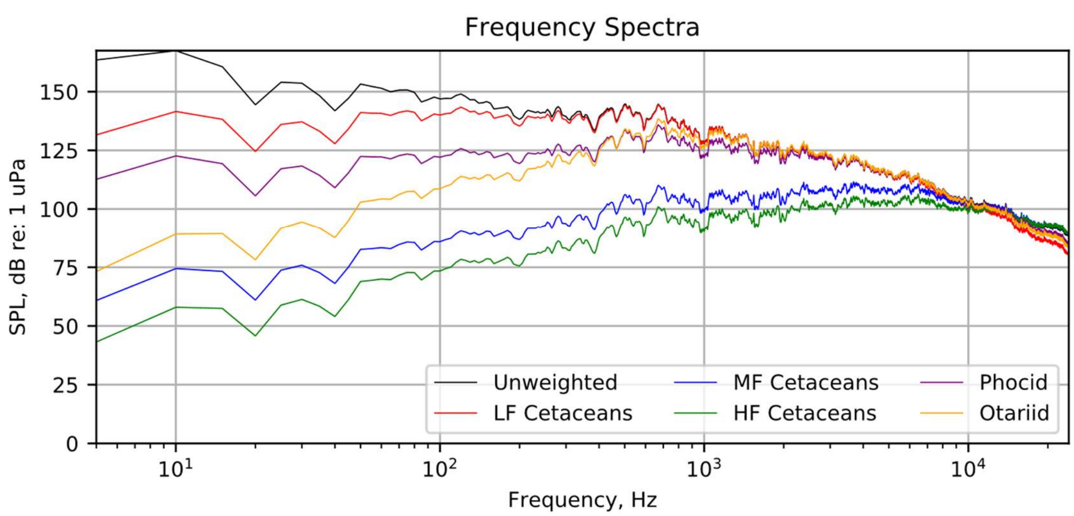

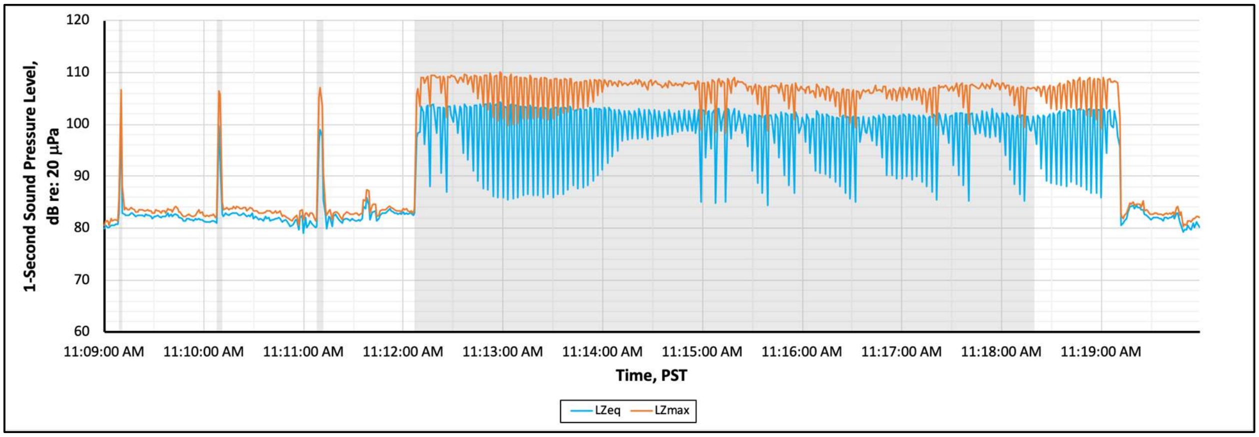
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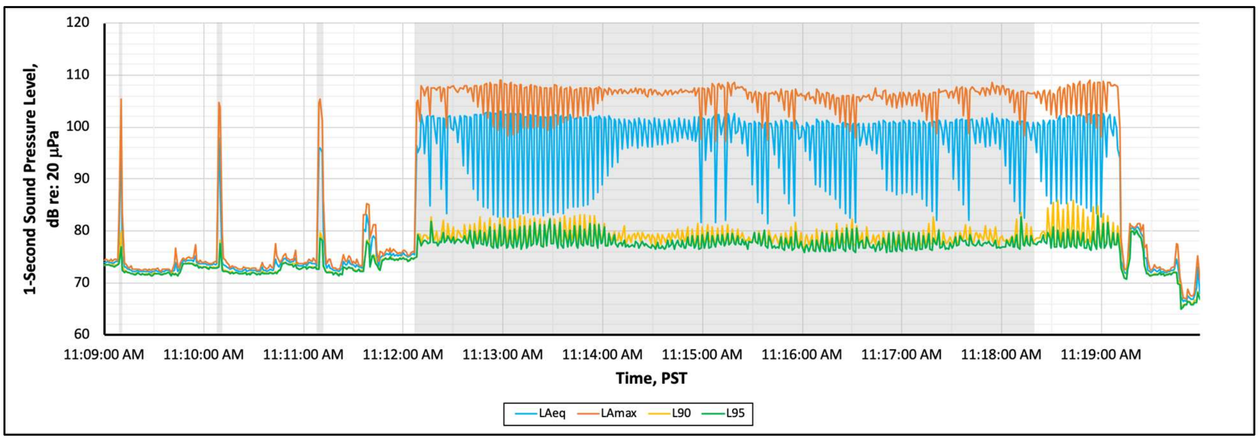
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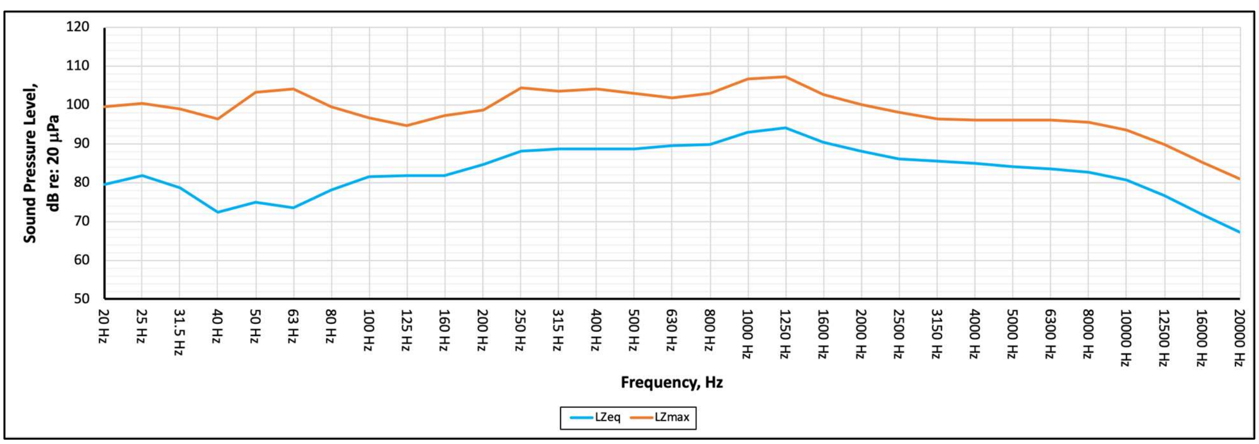
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16000 Hz
20000 Hz
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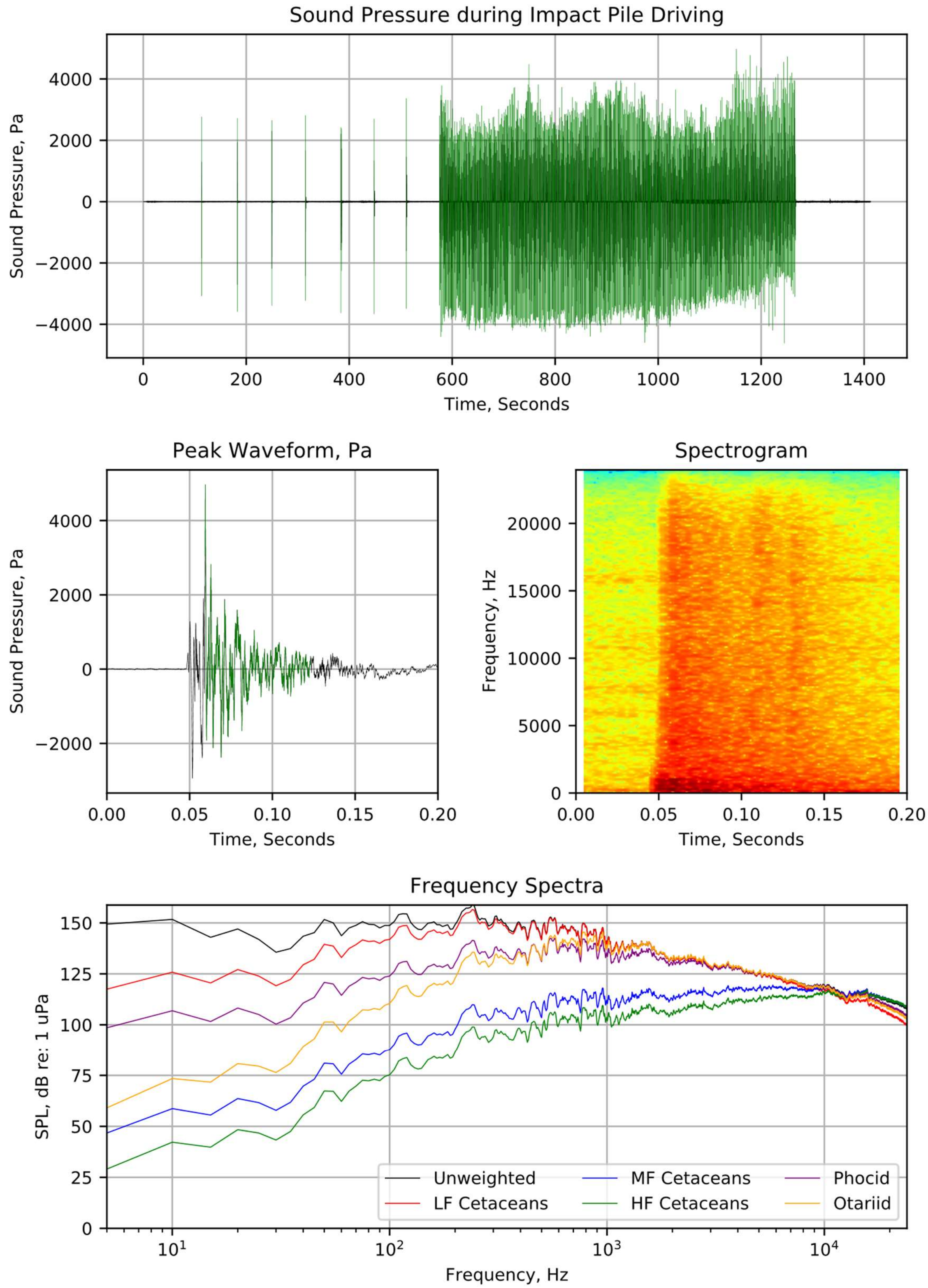
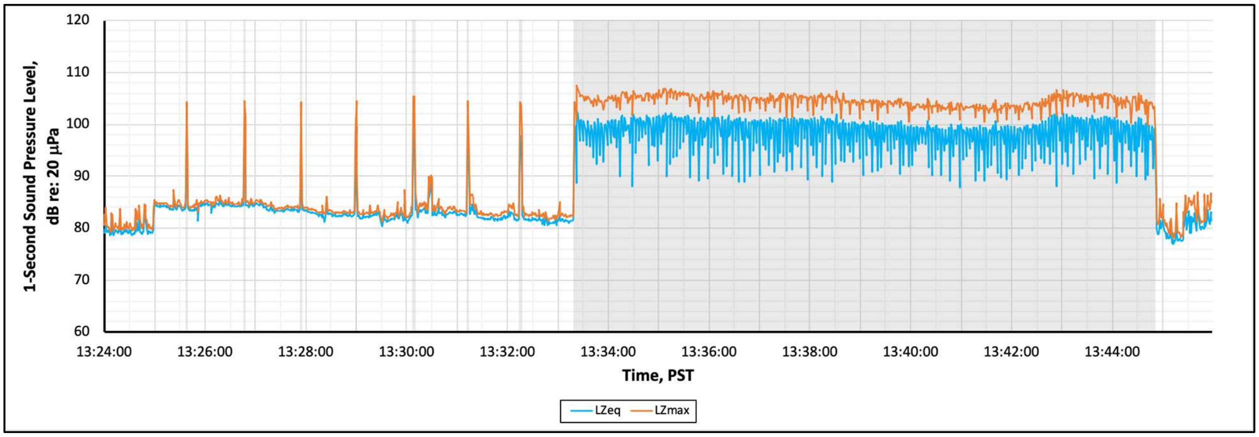
2.0 SLIP 2 BRIDGE SEAT (BATTERED PILES) 36-INCH STEEL PIPE PILES

PILE – 4

January 17, 2020

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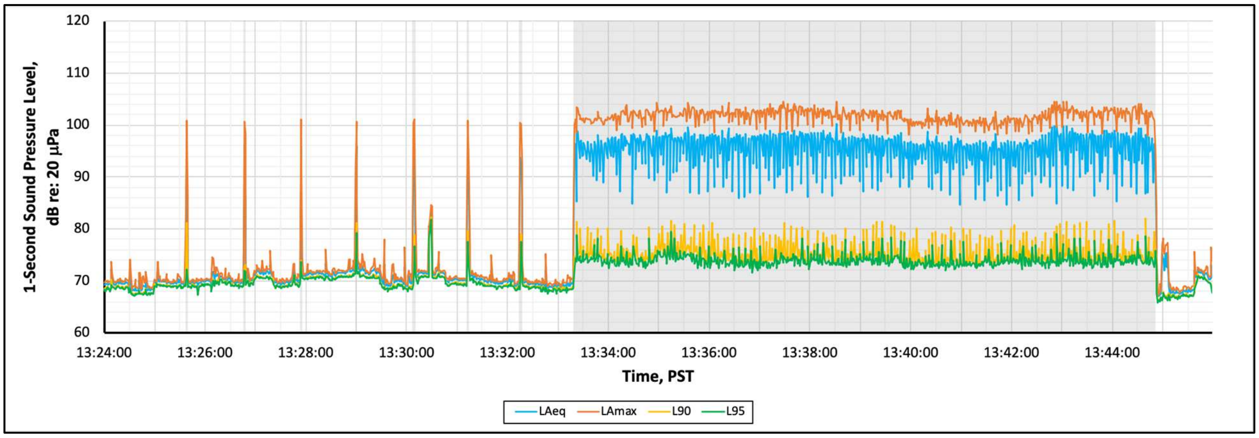
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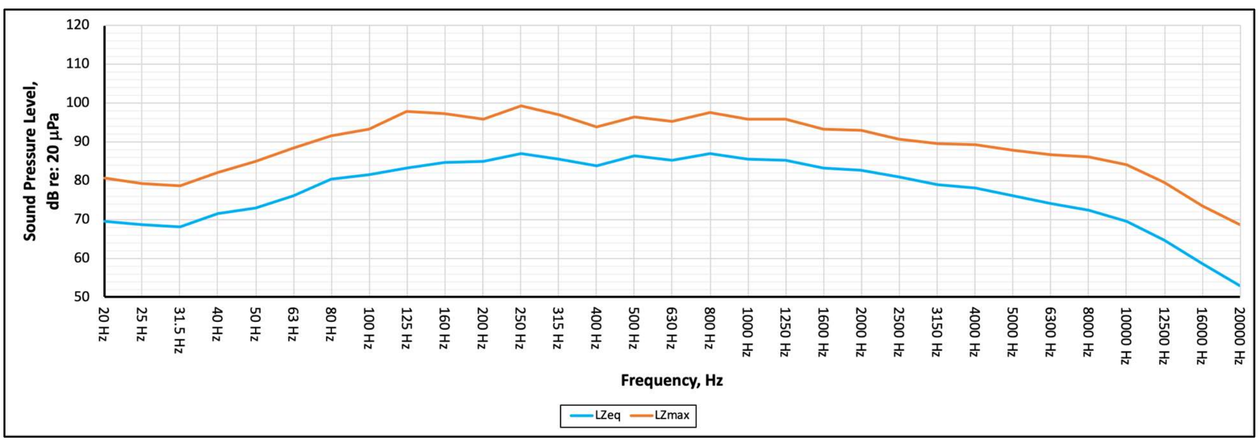
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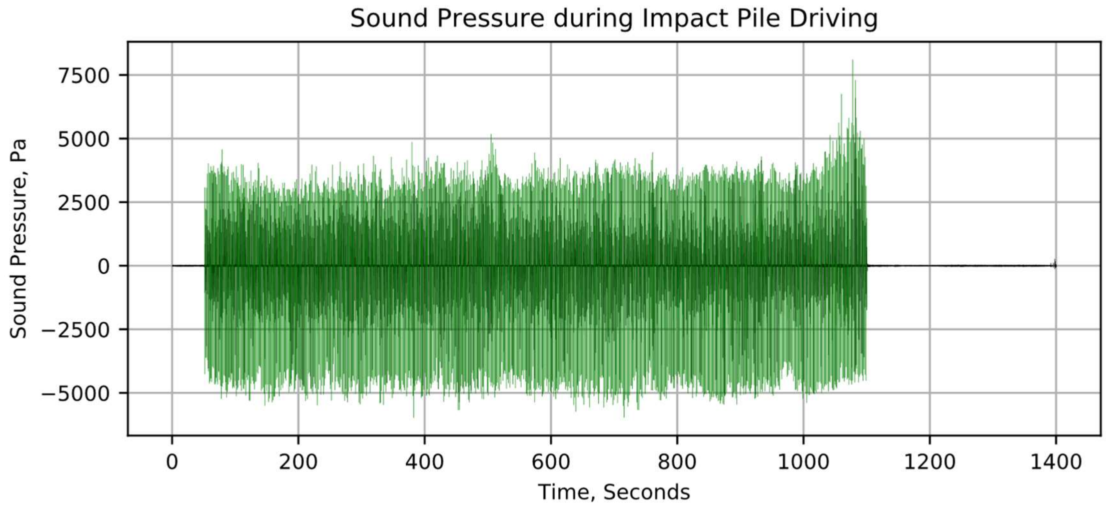

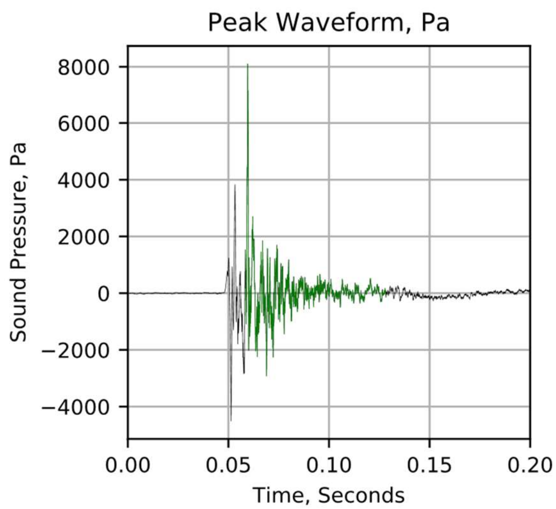

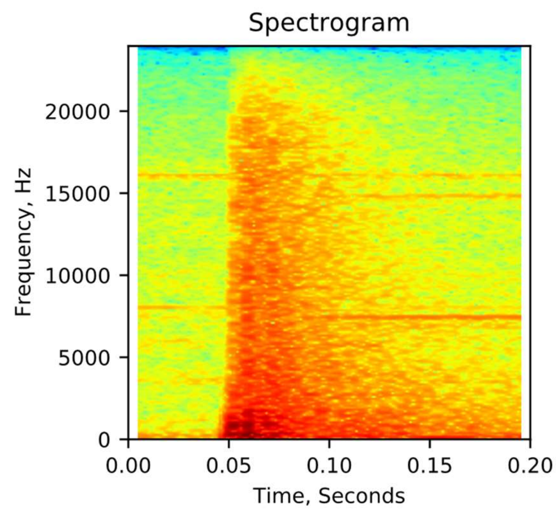

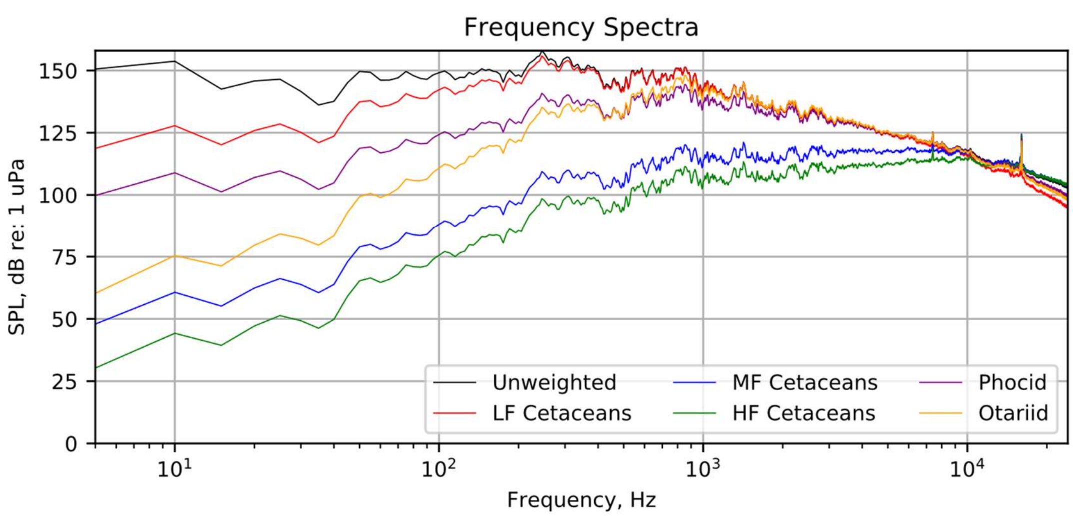

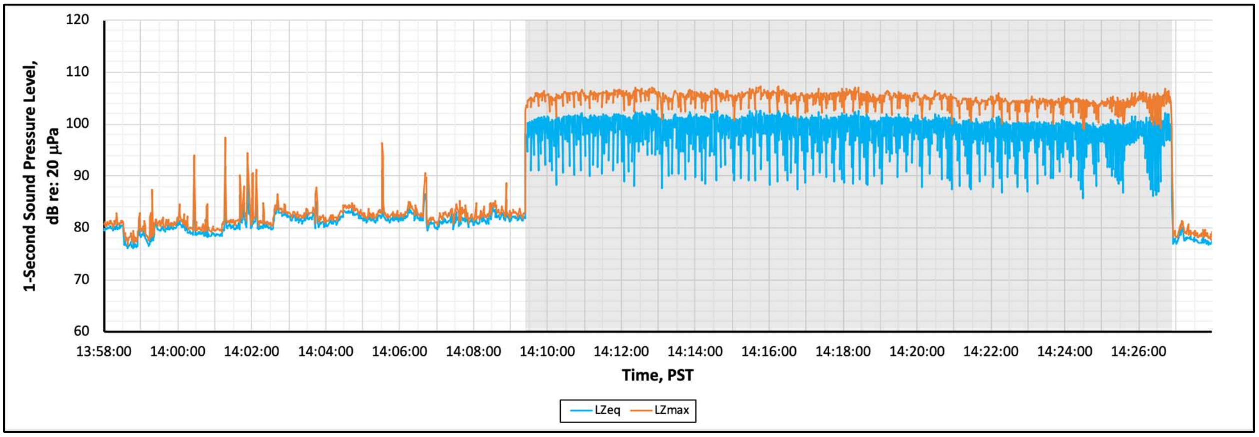
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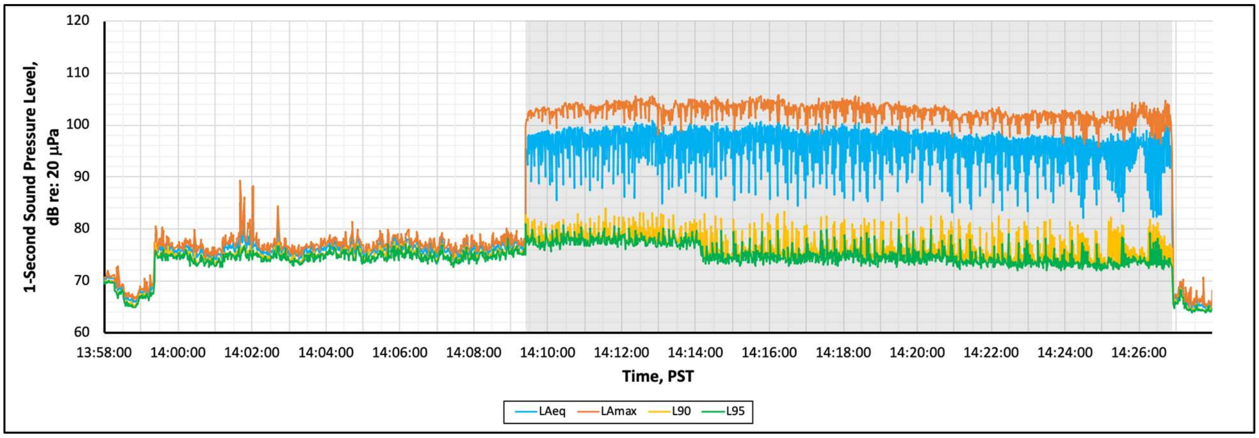
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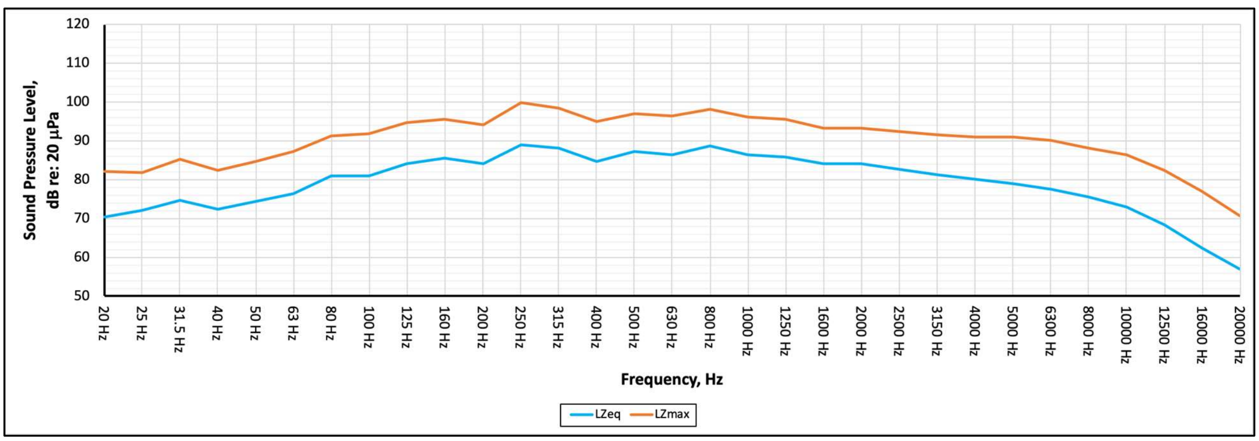
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10000 Hz
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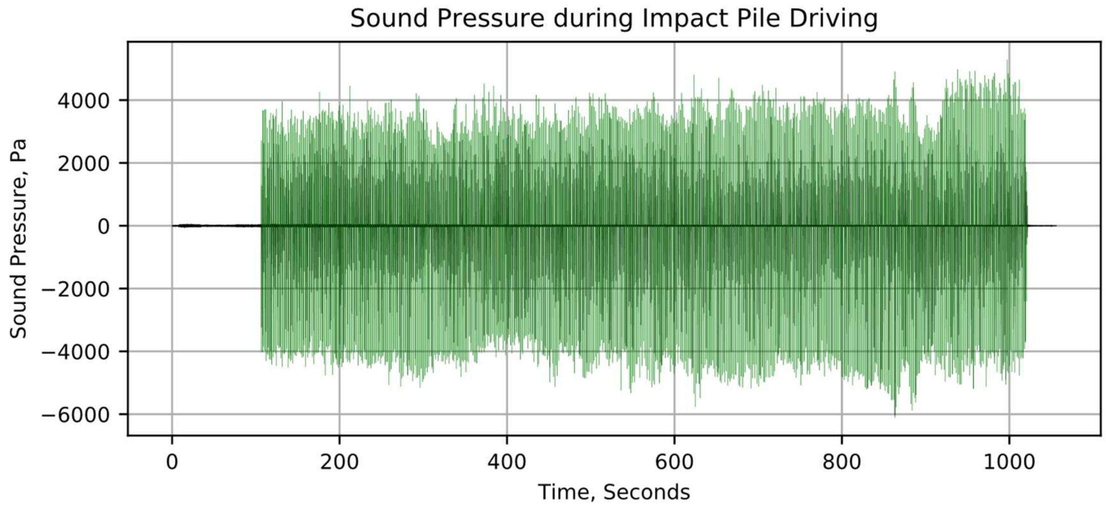
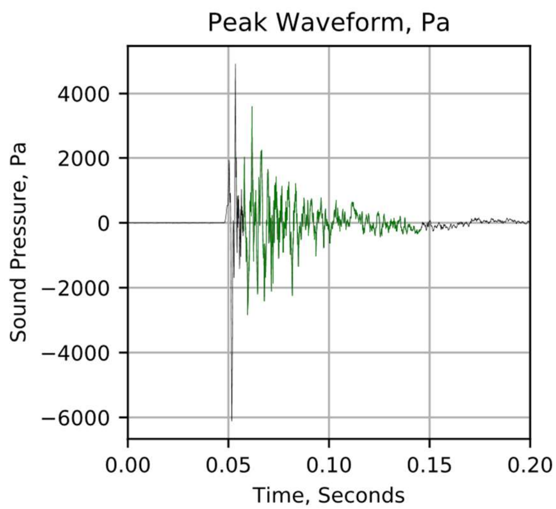
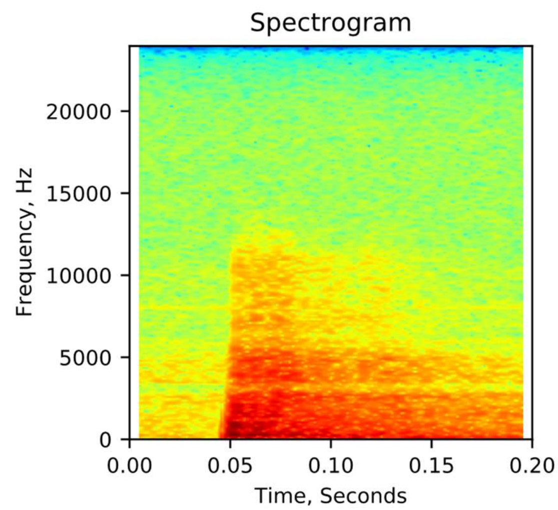
16000 Hz
20000 Hz
Frequency, Hz
LZeq
LZmax

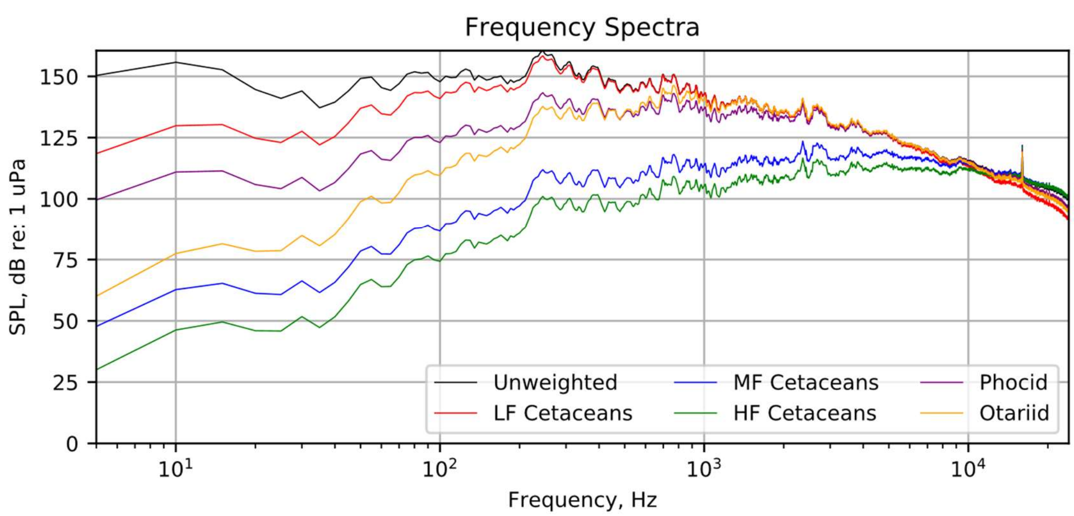
PILE – 2

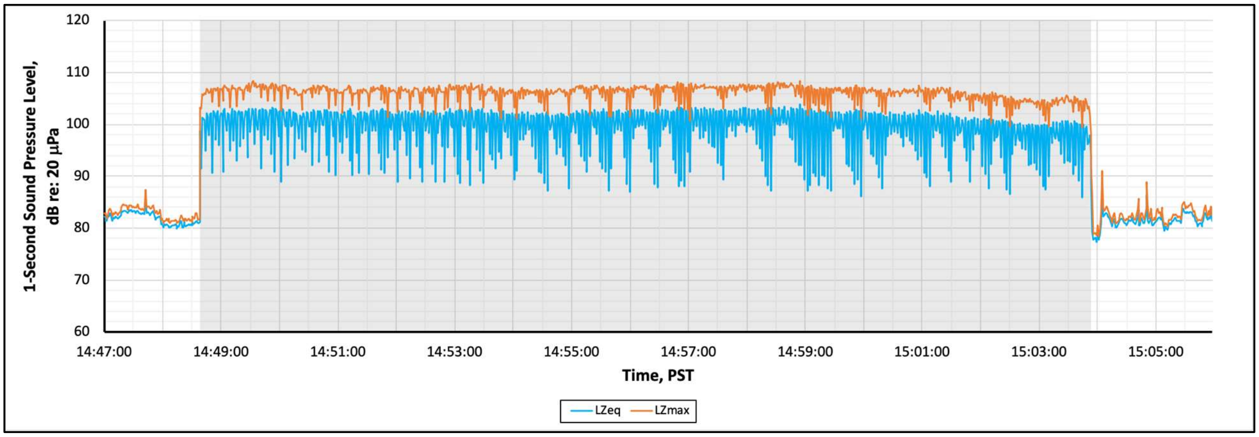
January 17, 2020







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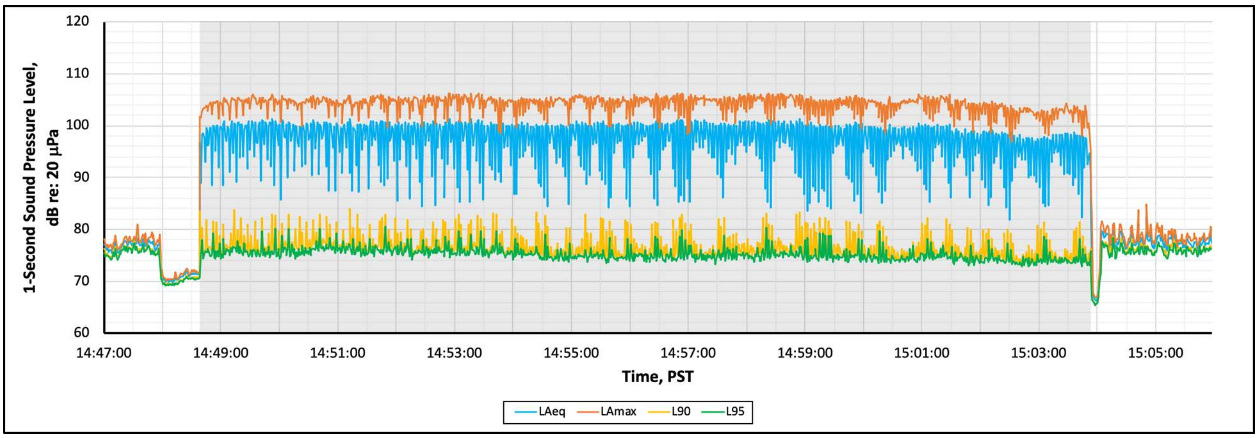
Time, PST
LZeq
LZmax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Time, PST
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LAmax
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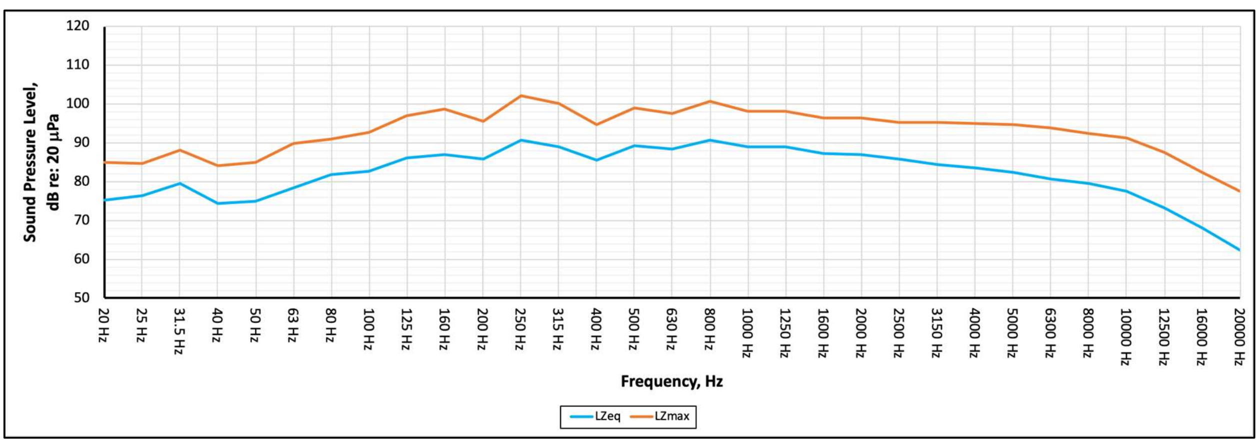
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1250 Hz
1600 Hz
2000 Hz
2500 Hz
3150 Hz
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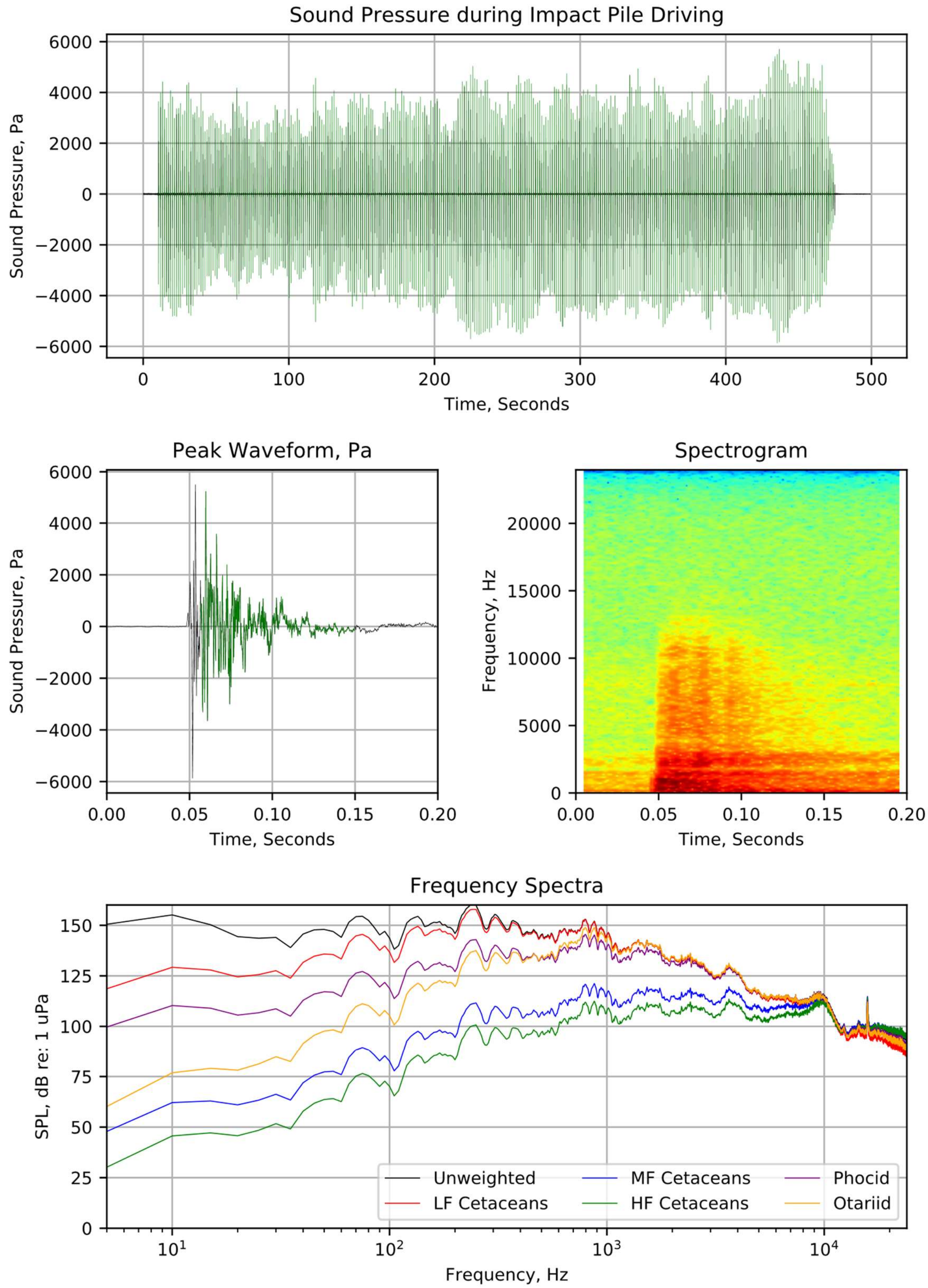
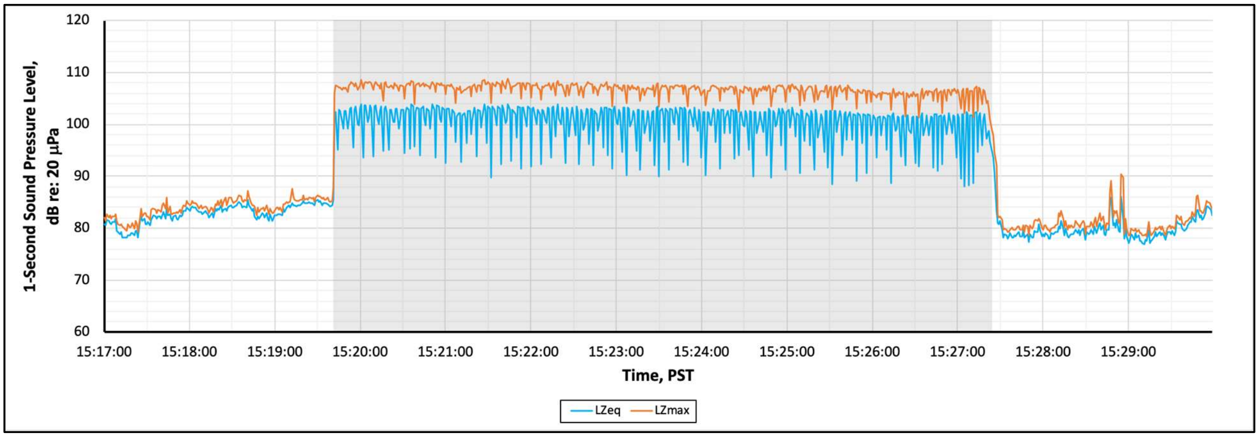
Frequency, Hz
LZeq
LZmax

PILE – 1

January 17, 2020

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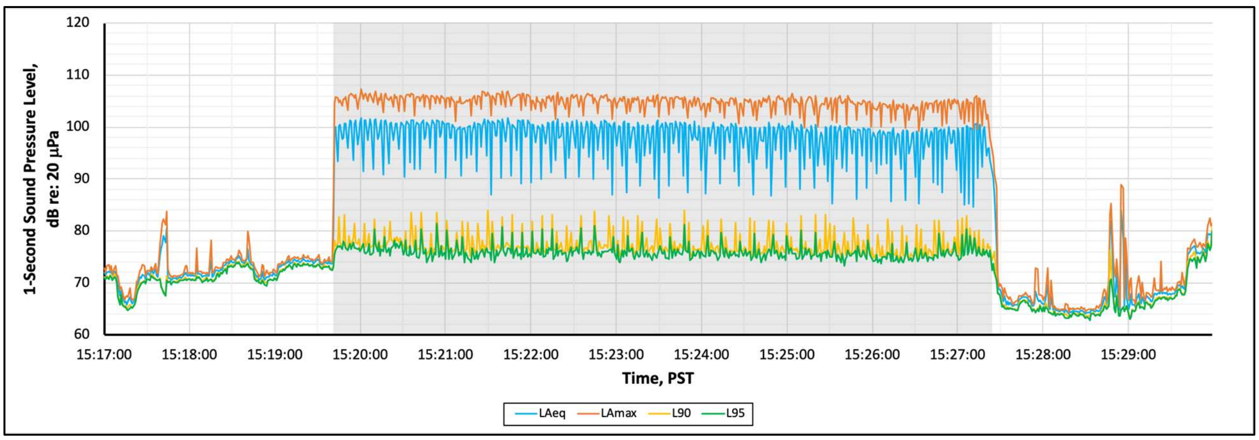
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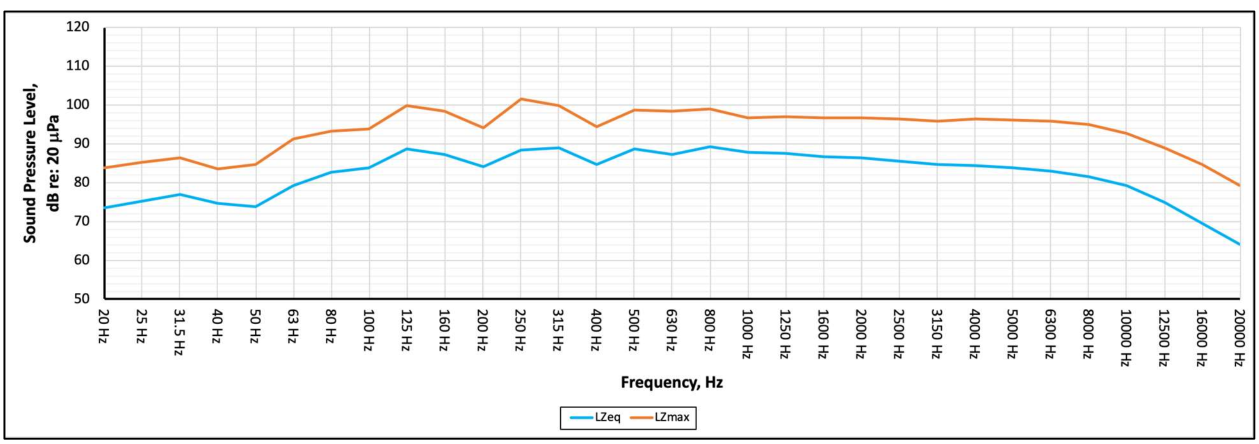
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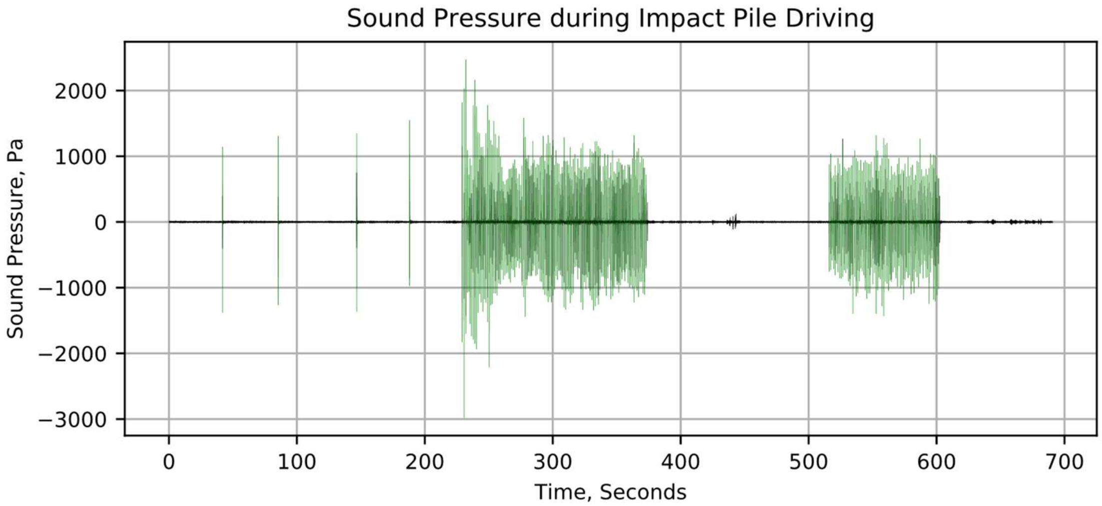
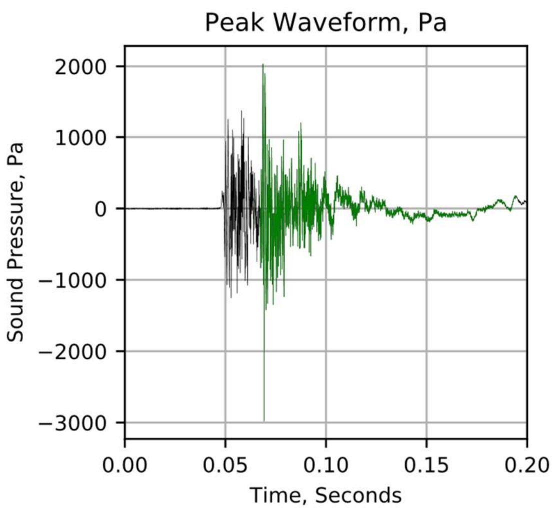
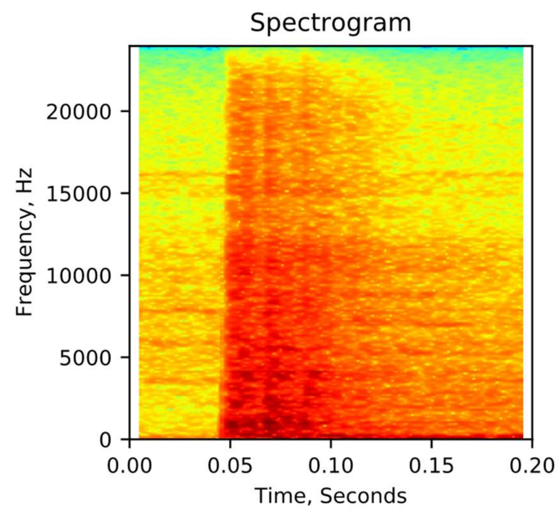
3.0 WEDGE PILING 24-INCH STEEL PIPE PILES

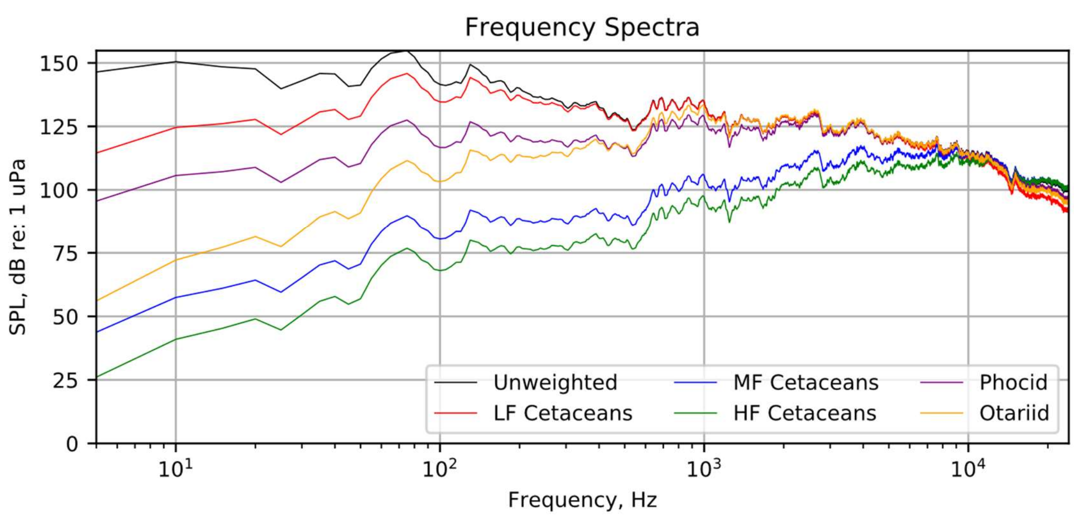
PILE W1

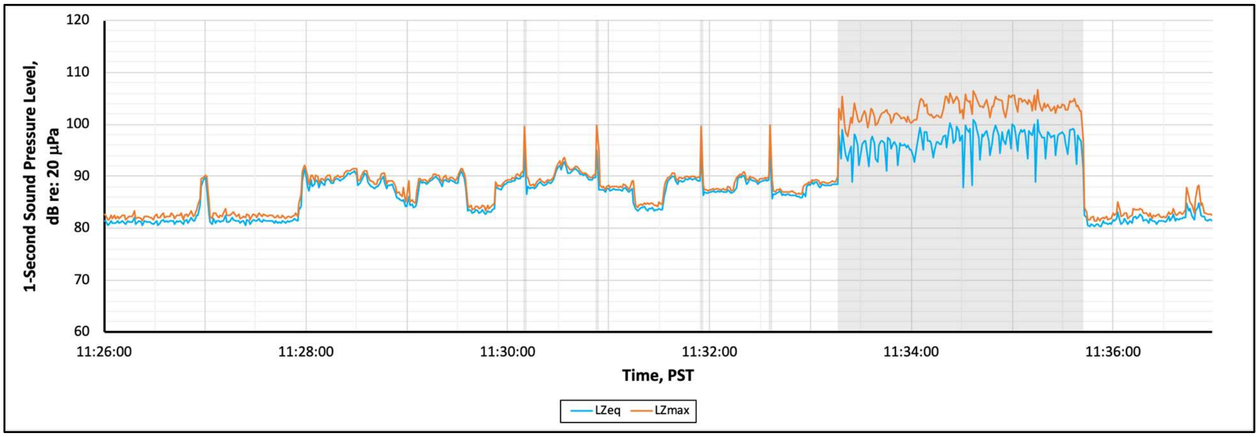
February 26, 2020







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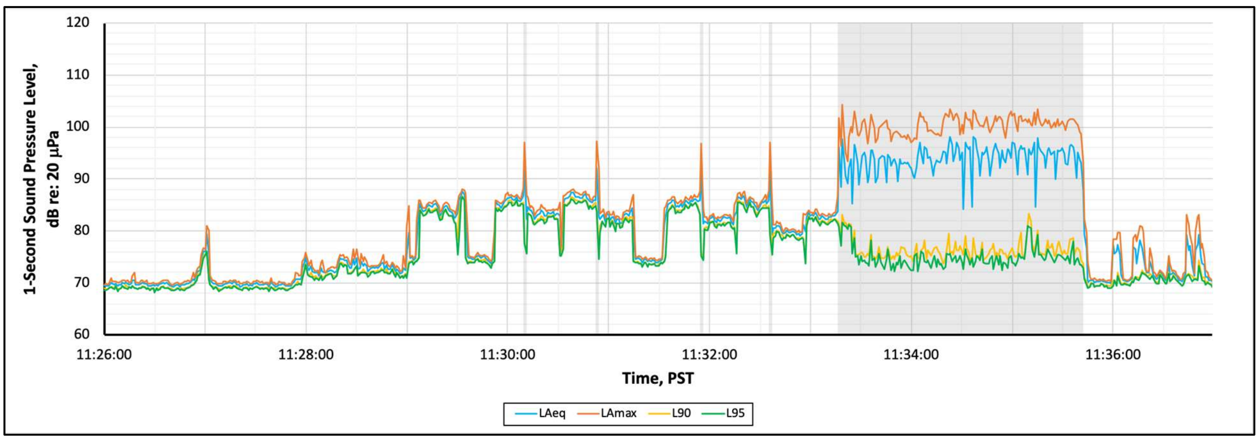
Time, PST
LZeq
LZmax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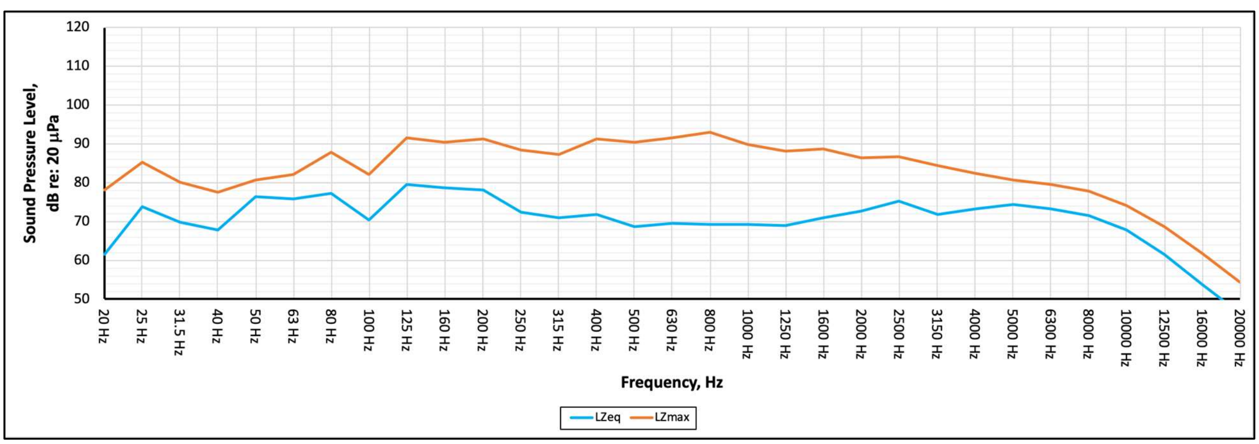
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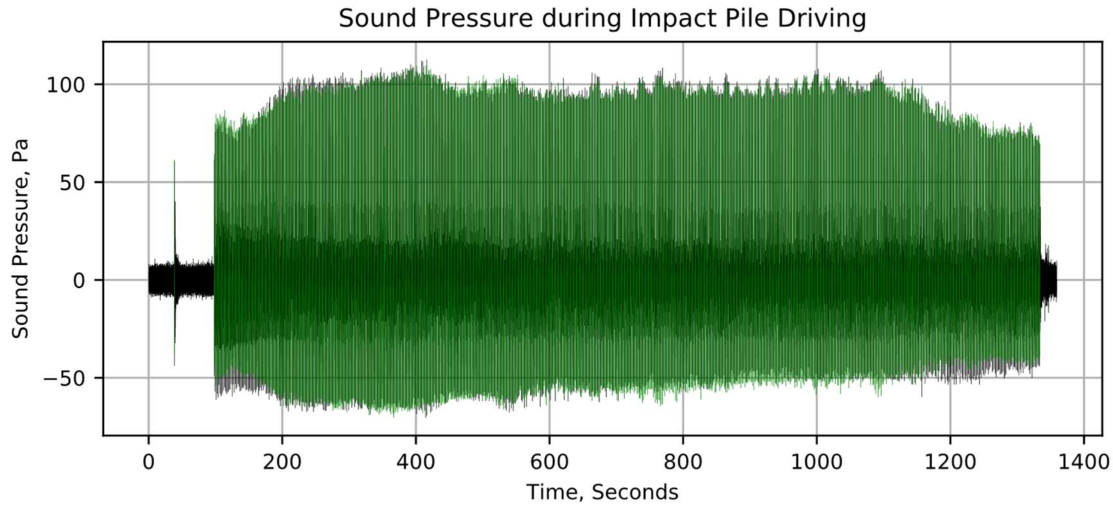
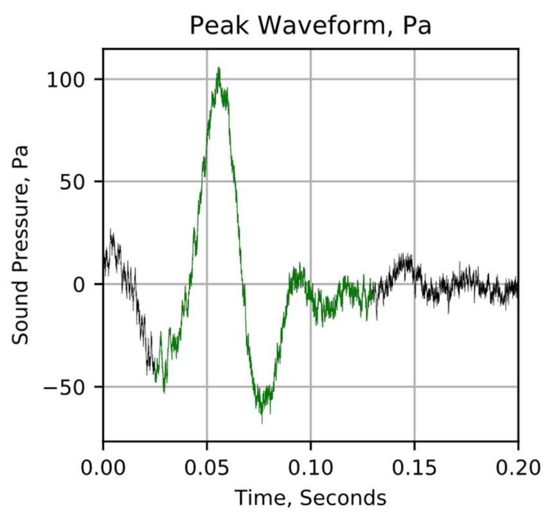
Frequency, Hz
LZeq
LZmax

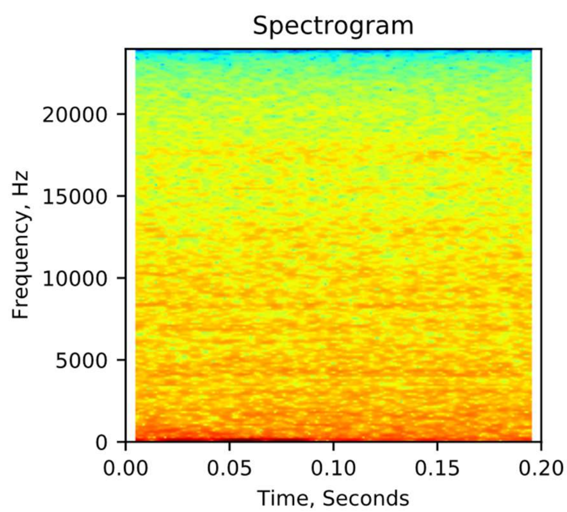
4.0 EAST SIDE OF NORTH TRESTLE (GROUP A) 36-INCH STEEL PIPE PILES

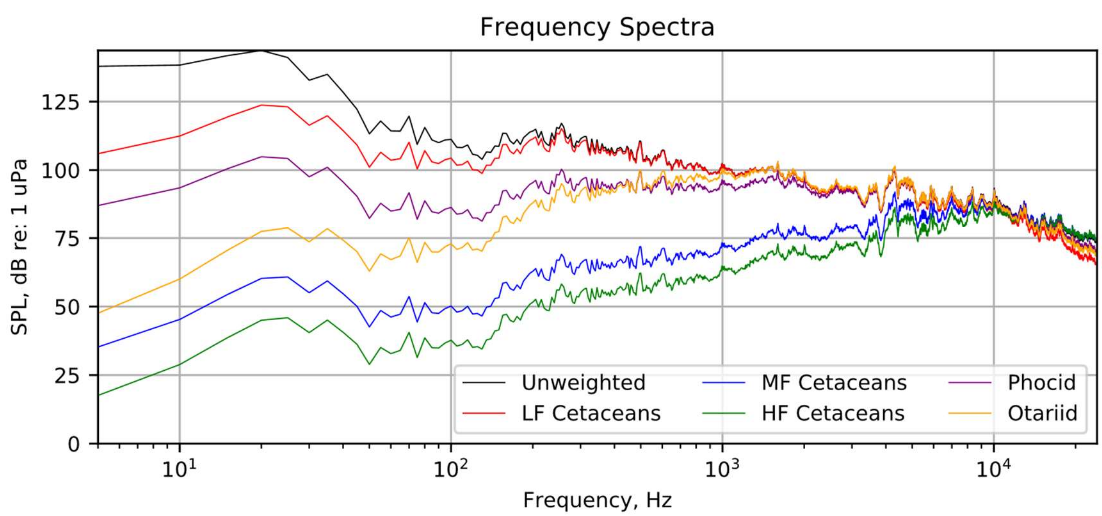
PILE E1.1-10 (ON-LAND)

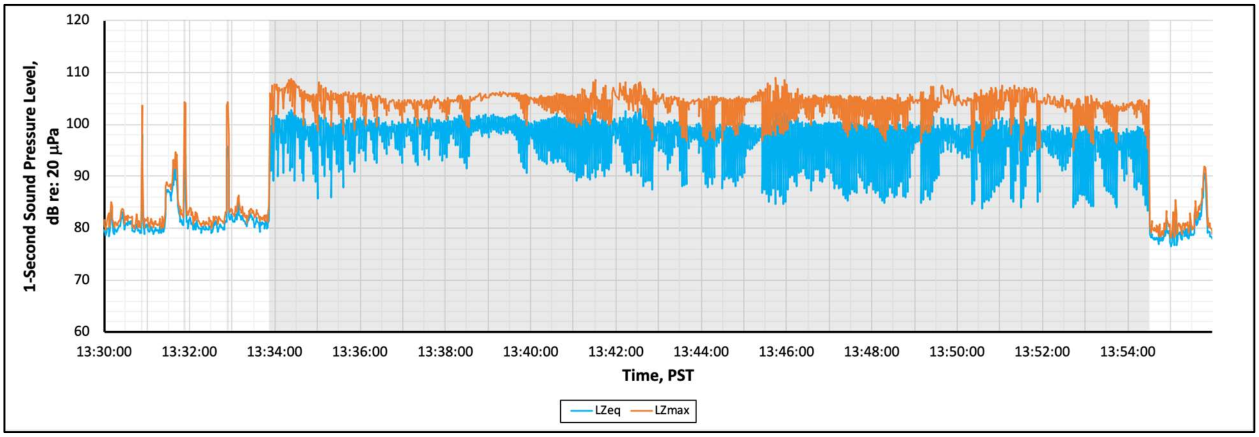
January 17, 2020







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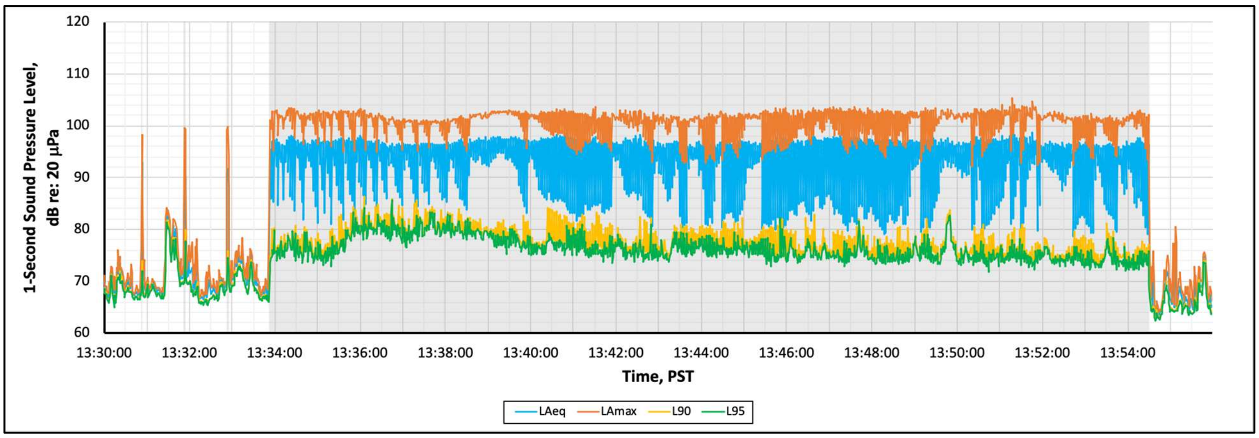
Time, PST
LZeq
LZmax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LAeq
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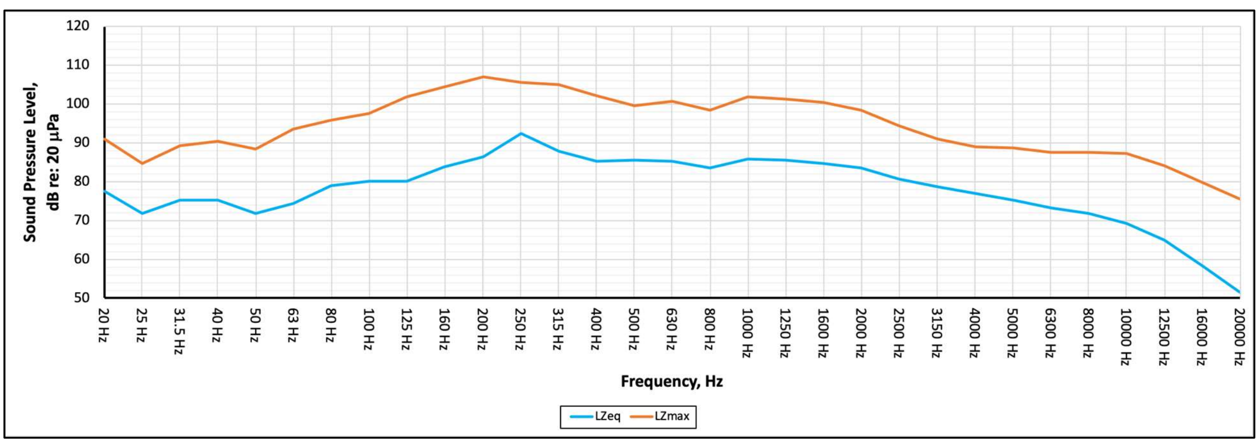
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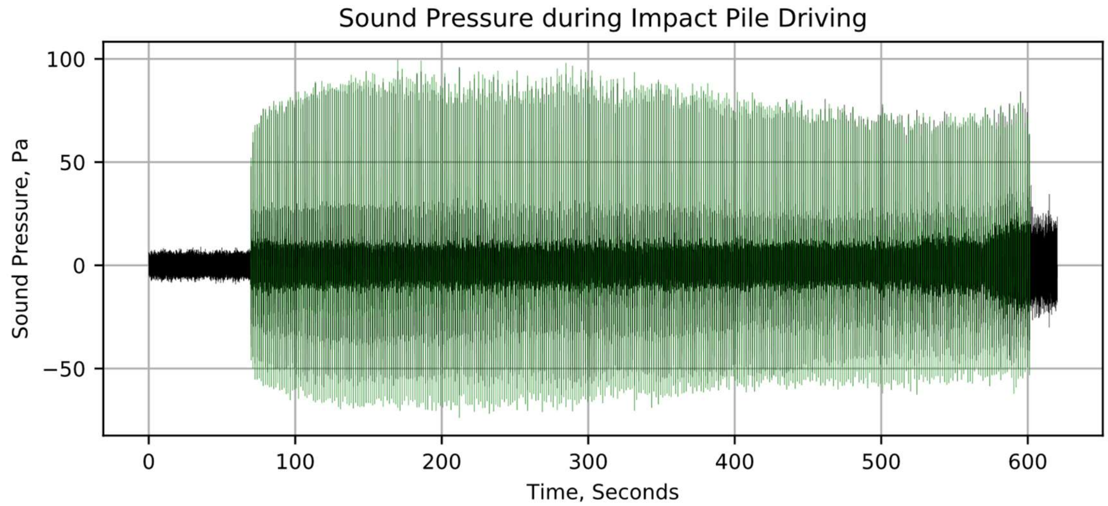
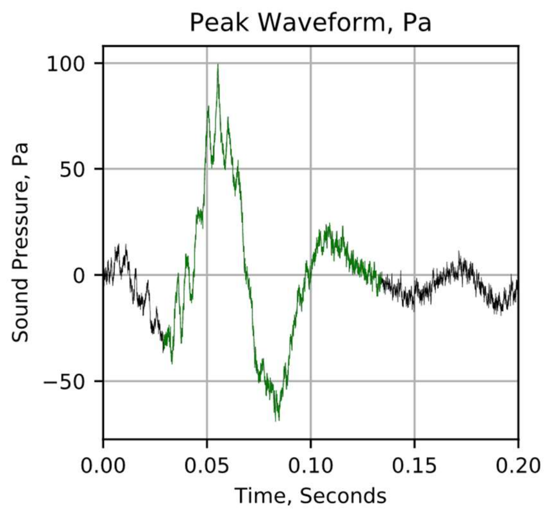
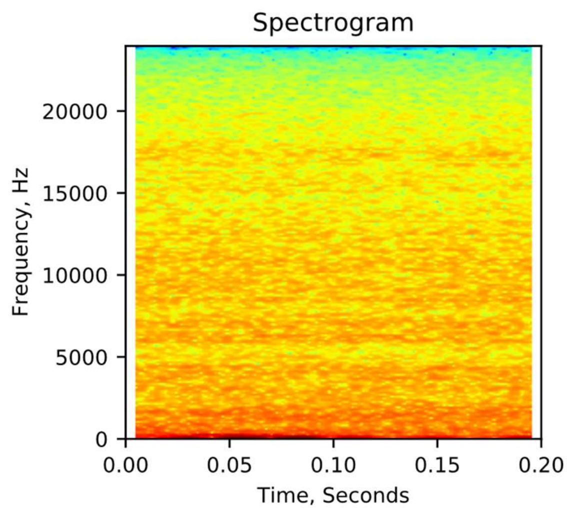
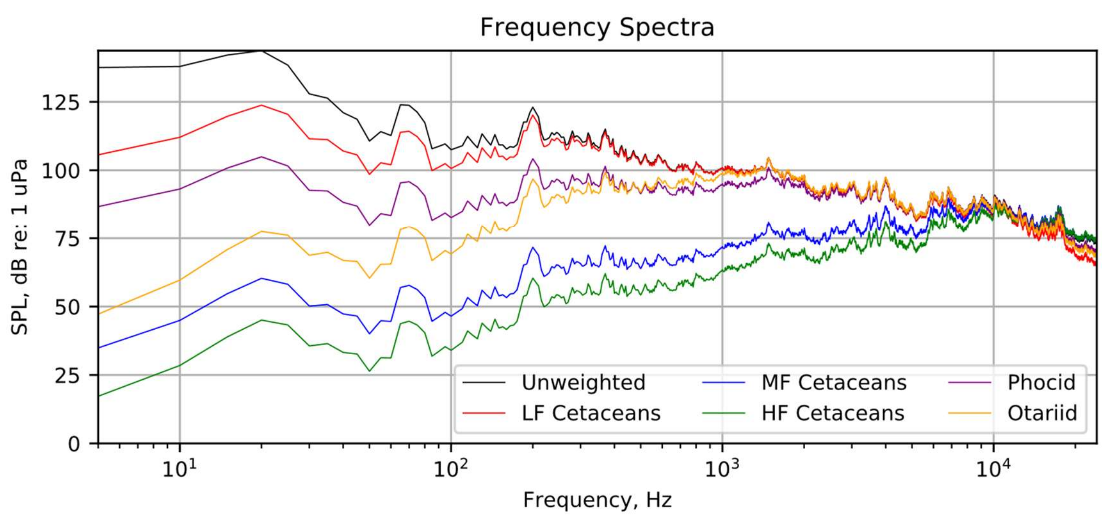
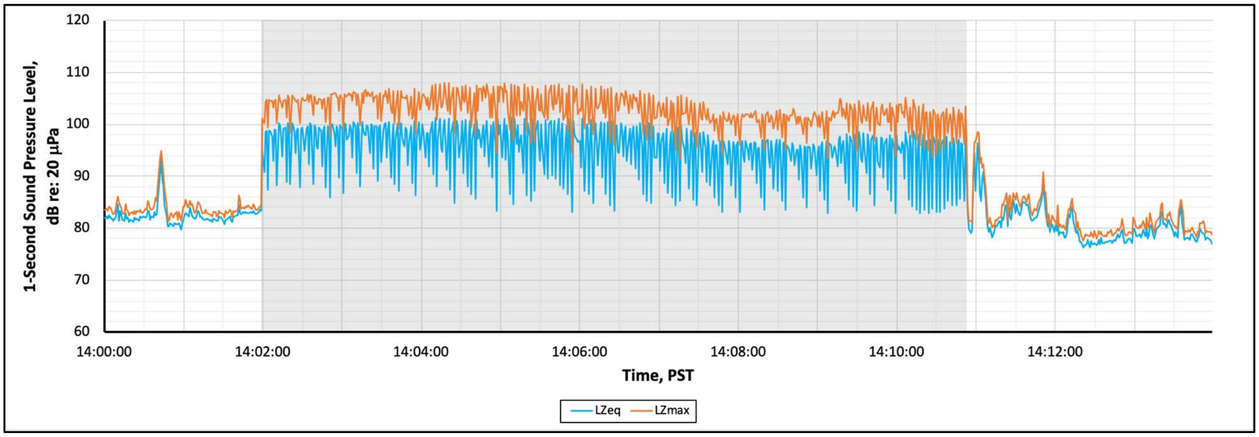
January 17, 2020







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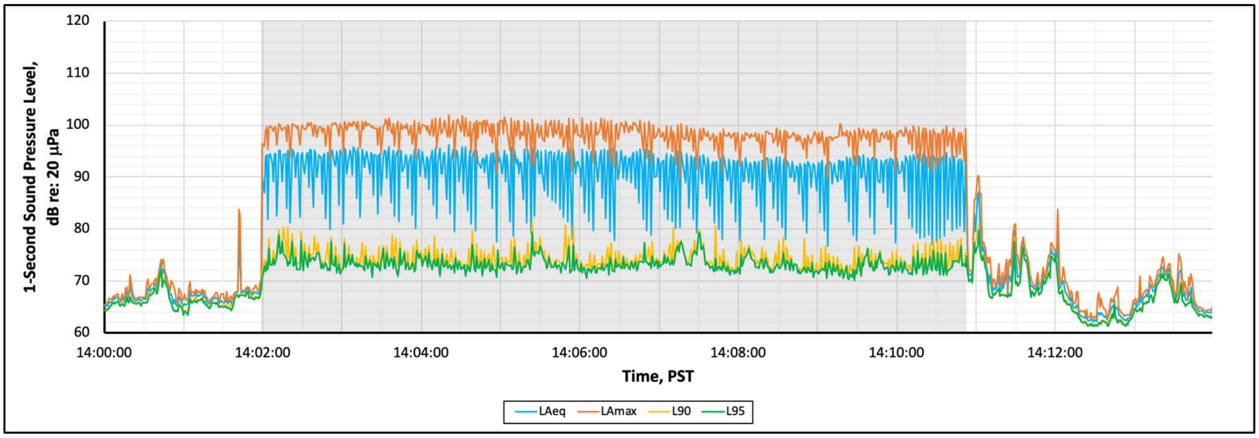
Time, PST
LZeq
LZmax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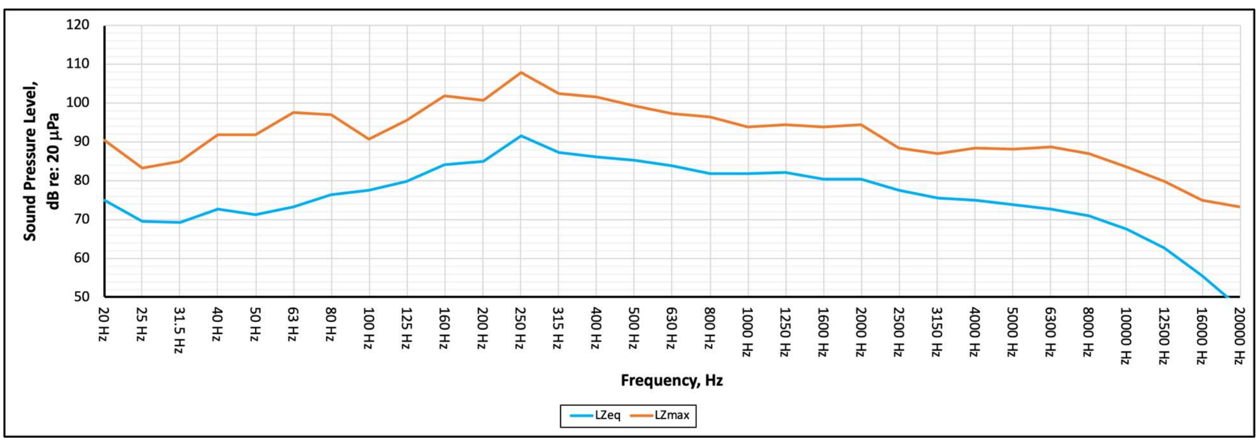
Time, PST
LAeq
LAmax
L90
L95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250 Hz
315 Hz
400 Hz
500 Hz
630 Hz
800 Hz
1000 Hz
1250 Hz
1600 Hz
2000 Hz
2500 Hz
3150 Hz
4000 Hz
5000 Hz
6300 Hz
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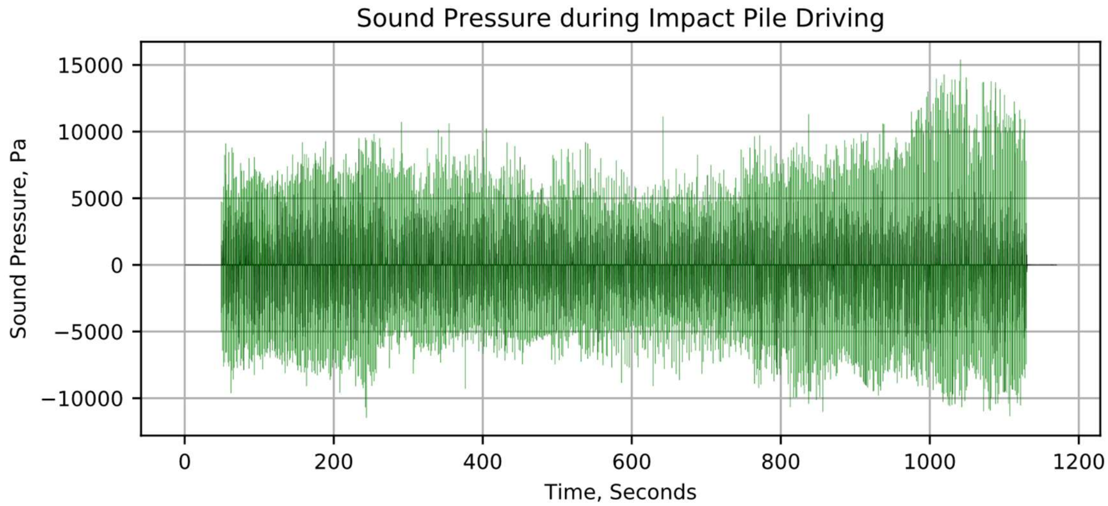
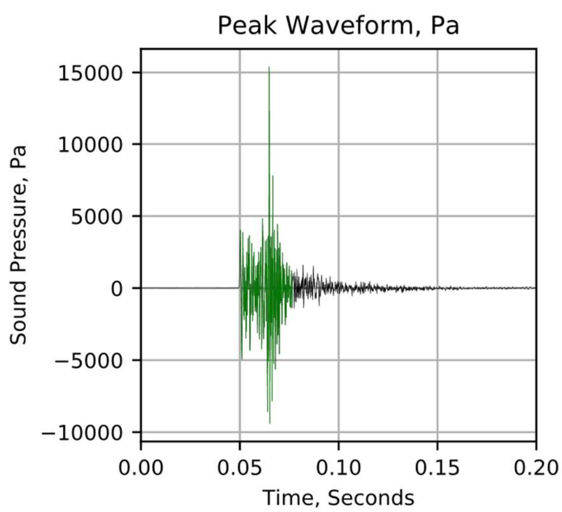
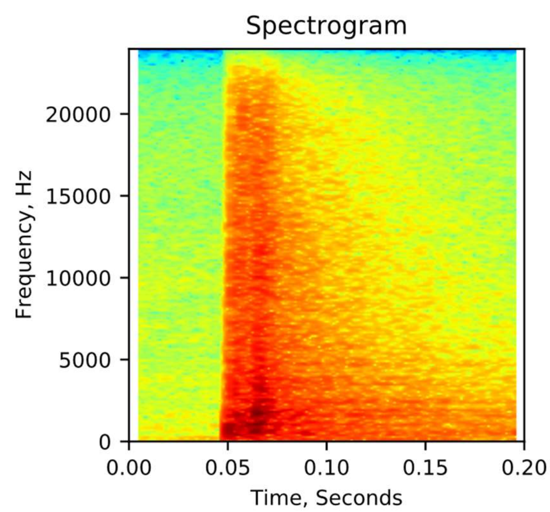
16000 Hz
20000 Hz
Frequency, Hz
LZeq
LZmax

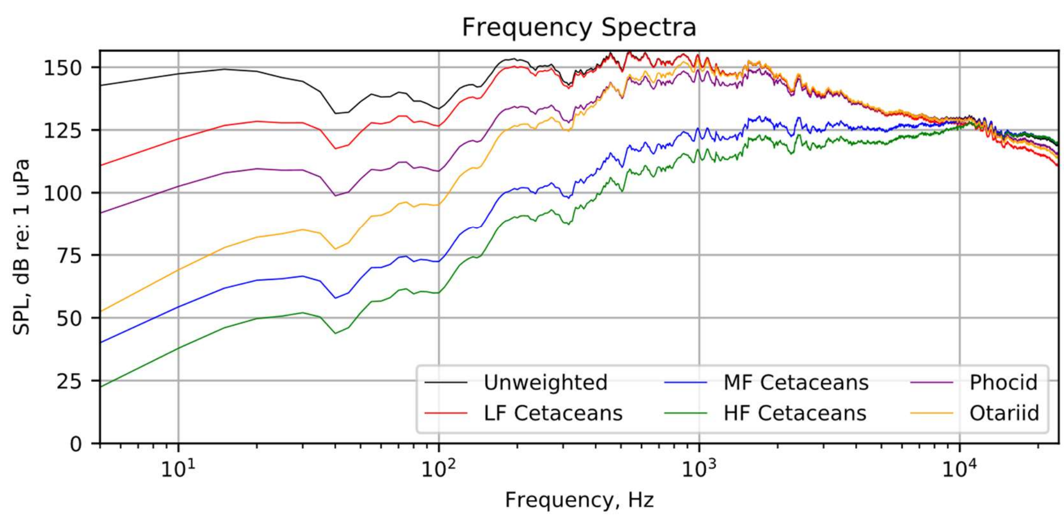
PILE E3-5

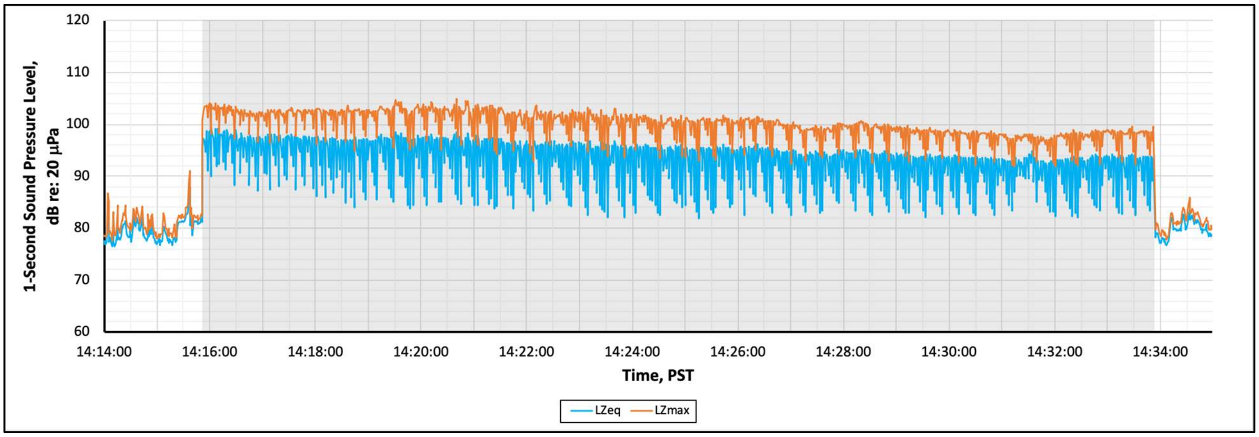
January 17, 2020







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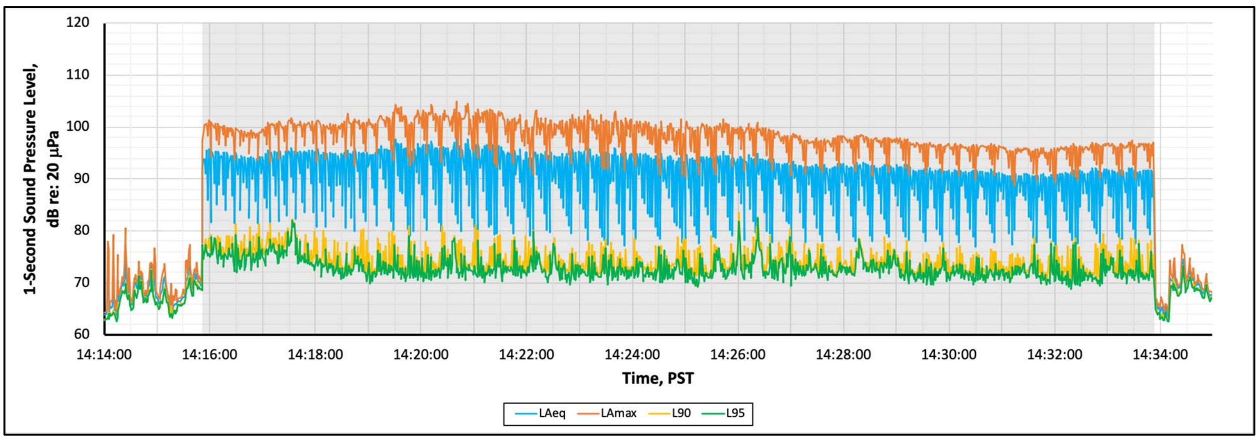
Time, PST
LZeq
LZmax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Time, PST
LAeq
LAmax
L90
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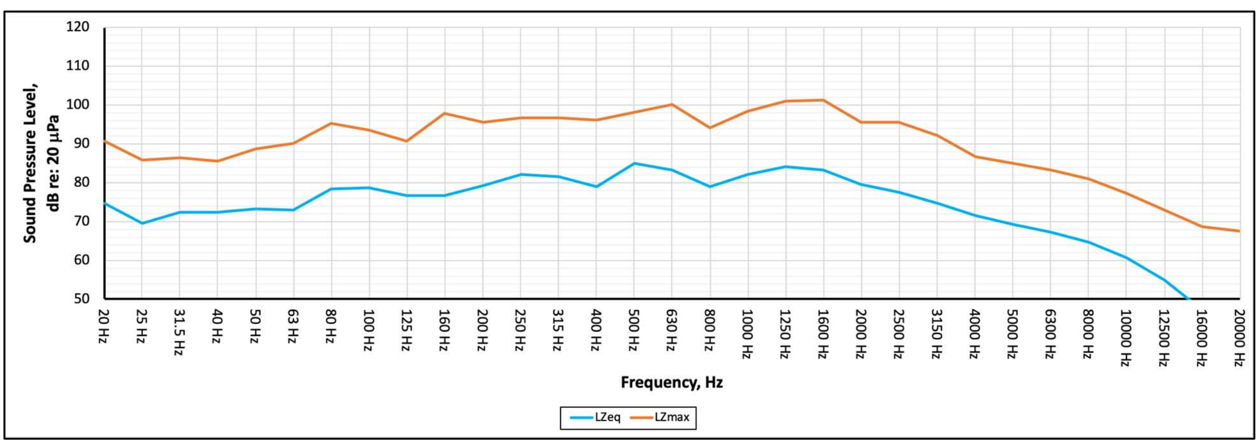

Sound Pressure Level, dB re: 20 µPa
Frequency, Hz
LZeq
LZmax

5.0 PILE DRIVER INFORMATION

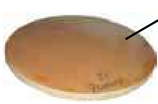
DELMAG D100-52 SINGLE ACTING DIESEL IMPACT HAMMER

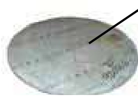
APE D100-52 Single Acting Diesel Impact Hammer

D100-52 in a bottom drive.

Optional Variable Throttle Control.

Cushion material.





Typical 54" offshore.

MODEL D100-52 (10.0 metric ton ram)

SPECIFICATIONS

Stroke at maximum rated energy	135 in (343 cm)
Maximum rated energy (Setting 4)	248,063 ft-lbs (334.88 kNm)
Setting 3	220,776 ft-lbs (298.05 kNm)
Setting 2	191,008 ft-lbs (257.86 kNm)
Minimum rated energy (Setting 1)	158,760 ft-lbs (214.33 kNm)
(Variable throttle allows for infinite fuel settings)	
Maximum obtainable stroke	150 in (381 cm)
Maximum obtainable energy	288,488 ft-lbs (391 kNm)
Speed (blows per minute)	34-53

WEIGHTS (Approximate)

Piston	22,050 lbs (10,000 kg)
Anvil	4,670 lbs (2,118 kg)
Anvil cross sectional area	482.8 in² (3114.83 cm²)
Hammer weight (includes hydraulic trip device)	47,000 lbs (21,318 kg)
Typical operating (weight with offshore leader)	Consult Factory

CAPACITIES

Fuel tank (runs on diesel or bio-diesel)	40.3 gal (153 liters)
Oil tank	8.3 gal (31.5 liters)

CONSUMPTION

Diesel or Bio-diesel fuel	7.8gal/hr (30 liters/hr)
Lubrication	0.67 gal/hr (2.5 liters/hr)
Grease	8 to 10 pumps every 20 minutes of operation time.

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

STANDARD OFFSHORE LEADER

8"x54" for 48" piles and under	Consult Factory

MINIMUM BOX LEAD SIZE/OPERATING LENGTH

Minimum box leader size	8 in x 37 in (20.32 cm x 94 cm)
Operating length for offshore leader	396 in (1005.84 cm)

Corporate Offices
7032 South 196th
Kent, Washington 98032 USA
(800) 248-8498 & (253) 872-0141
(253) 872-8710 Fax

Visit our WEB site:
www.apevibro.com
e-mail: ape@apevibro.com

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

APE D62 SINGLE ACTING DIESEL IMPACT HAMMER

APE Model D62-52 Single Acting Diesel Impact Hammer

D62-52 in a stand-off driving Kingpile.

MODEL D62-52 (6.2 metric ton ram)

SPECIFICATIONS

Stroke at maximum rated energy	144 in (366 cm)
Maximum rated energy (Setting 4)	164,052 ft-lbs (222.42 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	150 in (381 cm)
Maximum obtainable energy	178,862 ft-lbs (243 kNm)
Speed (blows per minute)	34-53

WEIGHTS (Approximate)

Piston	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 DB26 and H-beam 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 20 minutes of operation time.

Optional Variable Throttle Control.

STRIKER PLATE

Weight	1,036 lbs (470 kg)
Diameter	25 in (63.5 cm)
Area	491 in² (3167.74 cm²)
Thickness	8 in (20.32 cm)

CUSHION MATERIAL

Type/Qty	Micarta / 2 each
Diameter	25 in (63.5 cm)
Thickness	1 in (25.4 mm)
Type/Qty	Aluminum / 3 each
Thickness	1/2 in (12.7 mm)
Diameter	25 in (63.5 cm)
Total Combined Thickness	3.5 in (8.89 cm) 491 in²
Area	(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)

Corporate Offices
7032 South 196th
Kent, Washington 98032 USA
(800) 248-8498 & (253) 872-0141
(253) 872-8710 Fax

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e-mail: ape@apevibro.com

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

6.0 BUBBLE CURTAIN INFORMATION

System Design Calculations:

Compressed Air Bubble Curtain

Design:	**Washington State DOT** **Colman Dock Project**
For:	**Pacific Pile & Marine, LLC** **Seattle, Washington**
System:	**Bubble Curtain Performance Calculations**
System Number:	**2017-47-72-1B**
Date:	**14-Sep-17**
By:	**jwk**

JAMES W. KREUTER
STATE OF WASHINGTON
26117
REGISTERED PROFESSIONAL ENGINEER
9-14-17

Rev B

VANGUARD MARINE, PLLC
P.O. Box 505 Quilcene WA 98376
Phone (206) 595-9203 email jmkreuter@vanguardmarineplc.com

Bubble Curtain Performance Calculations	Sheet: 1 of: 23

A. REVISIONS

REV A

Date	Item	Description
9-14-2017	1)	Corrected quantity of air bubbler rings used for "confined bubbler ring" needed when driving batter piles. The original quantity used WAS (7), and now IS (1). HDPE Ring only needs to protrude a minimum distance of 0.50-FT (6-IN) above water level in order to function as required. See sheets 19-22.

REV B

Date	Item	Description
9-14-2017	1)	Modified calculations to consider and include air manifold and pertinence of it in system performance (including available air flow rate). Added sheet 12. Modified calculation CONCLUSION to suit.

Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

Bubble Curtain Performance Calculations	Sheet: 2 of: 23

B. TABLE OF CONTENTS

Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

Bubble Curtain Performance Calculations	Sheet: 3 of: 23

C. DISCUSSION

The following calculations are provided to demonstrate the performance of a Bubble Curtain Assembly design that will be used to generate a noise attenuating curtain of bubbles during pile driving associated with work being conducted as part of the rebuilding of the Washington State DOT Colman Dock in Seattle, WA. A previously constructed bubble curtain system will be used (and modified) to satisfy the contractual requirements associated with the noise attentuation portion of the project specification. The bubble curtain system is to engulf in bubbles over the full depth of the water column at all times that the impact pile driver is in use.

The bubble curtain equipment will take two general forms: 1) Unconfined bubble curtain arrangement, and 2) Confined bubble curtain arrangement. The unconfined arrangement will be used to provide noise attenuation for vertical piles that are being driven into the mud. The confined arrangement will be used while driving batter piling.

The unconfined bubble curtain assembly equipment consists of air compressors that will deliver supply air to a fabricated air system manifold. The manifold splits the supply air into (up to) fourteen supply hoses that provide supply air to (up to) seven air bubbler rings that are positioned around the pile being driven. The air bubbler rings are positioned at regular 7-FT intervals beginning at the mud line and spaced vertically up to the water surface. The confined bubble curtain system includes ONLY one ring at the mud line.

This set of calculations will establish the number of air compressors required (including rated output) to satisfy the WSDOT specified air bubble flux density of 32.91-CFM per foot of bubbler ring. This installation will consist of three bubbler rings used in water depths of up to 50-FT deep.

It is assumed that the existing equipment has been fabricated in accordance the the intent of the project specificaions and that the equipment performs as described in the specifications. The purpose of this set of caclulations is to serve as a check on equipment performance and to establish, using the characteristics of compressible gas (ie. Compressed air) the flowrate and pressure of air delivered to the equipment to achieve the specified bubble flux for the water depths required and the as-built bubbler rings (with the established air orifice size and count).

Assumptions made to support this set of calculations are shown on next sheet.

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Bubble Curtain Performance Calculations	Sheet: 4 of: 23

D. ASSUMPTIONS & CRITERIA

1) The following industry accepted nomenclature is used throughout this analysis:

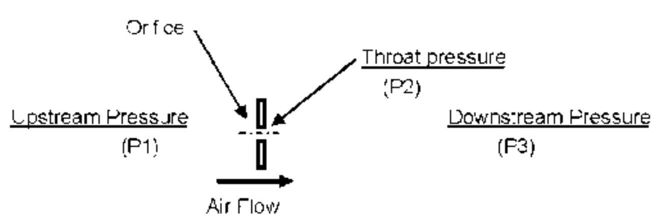
   SCFM = Air as measured at "standard" conditions (Temp = 60-F, 14.7-PSIA)

   ACFM = Air as measured at "actual" conditions (Temp = xx-F, xx-PSIA)

2) The pressure drop calculations made to estimate the frictional losses in the system air piping consider the "longest run" in the system. If the system will perform as required through the longest run, performance through all shorter runs of piping will be at least as good as determined for the longest run.

3) The bubble curtain is created by delivering compressed air to a pipe formed into a ring that has several holes drilled through the pipe ring that allow air bubbles to discharge. The drilled holes act as "orifices" through which the compressed air passes. Any reference to orifices in this set of calculations indicates these holes.

4) Compressed gases, when passing through an orifice, will demonstrate different behaviors depending upon flow and pressure parameters. If the upstream pressure (upstream of the orifice) is high enough, and the downstream pressure is low enough, the upstream pressure will cause enough flow through the orifice to create what is known as a "critical flow" condition. For fully developed "critical flow", the velocity of the gas through the throat of the orifice reaches a sonic velocity. If this occurs, it can be shown that the behavior of the gas can be predicted using certain formulae. If the downstream pressure is higher, the relative pressures cannot reach "critical flow" and instead achieve what is referred to as "subcritical flow". In this case, different formulae are used to predict the behavior of the gas. In these calculations, it is shown that the submergence of the bubbler ring under the static head of the water column prevents full "critical" flow from developing. Instead, the air flow calculations are based on "subcritical" flow, as shown in the calculations.



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Bubble Curtain Performance Calculations	Sheet: 5 of: 23

D. ASSUMPTIONS & CRITERIA

5) An orifice is a round sharp edged hole in a thin plate. The holes in the fish ring pipe are assumed to behave as do orifices - rather than like any form of nozzle. Critical ratios for compressed (perfect) gases apply accurately to rounded entrance nozzles. Their application to sharp edge orifices is rather approximate. In practice, the critical ratio is applied to either nozzle or orifice.

   For air between 0-DEG F and 250-DEG F, the critical ratio for air is: $r_c = 0.528$.

6) The air system schematic and details are shown in the Washington State Department of Transportation guidance drawing set, Drawing Numbers "S03.70" thru "S03.75" dated with "Submittal Date" of 2-28-2017 in all cases. These drawings developed for the Multimodal Terminal at Colman Dock.

7) The Bubble Curtain performance specification is provided in Washington Department of Transportation - Ferries Division project specification for the Seattle Multimodal Terminal at Colman Dock. See pages 255 through 258 (dated 2-28-2017).

8) The assumed hose size between the air compressors and the air system supply manifold assembly is 3"-Nom and the hose length is assumed to be 100-FT long. The hose is rubber-lined and assumed to be equivalent to steel pipe.

9) The assumed hose size between the air system supply manifold assembly and the (furthest) air bubbler ring is assumed to be 1"-Nom and the hose length is assumed to be 200-FT long. Rubber-lined hose assumed to be equivalent to steel pipe.

10) The compressor air will be filtered for oil mist prior to delivery to the system. The sizing and selection of the fillter will be provided elsewhere, by others.

11) For the unconfined bubble curtain arrangement, there will be up to (7) bubbler rings spaced at 7-FT intervals (first ring being positioned on mud) suitable for depths of up to 50-FT deep (water depth). The confined bubble curtain arrangement will be fabricated from a combination of steel with HDPE tube, also sized for 50-FT depths.

12) The seawater temperature (avg.) is assumed to be: **50** F

13) The specific gravity of seawater assumed is: **1.03** - -

14) The assumed atmospheric pressure is: **14.696** PSI

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Bubble Curtain Performance Calculations	Sheet: 6 of: 23

D. ASSUMPTIONS & CRITERIA

15) The assumed air temperature of the compressed air: **60** F

16) Criteria for the unconfined ring as follows:
The bubbler ring diameter is assumed to be: **68.875** IN
The number of holes in each ring (per WSDOT dwg): 1,134 holes
(assumes 1"-deducted from length of each half, each end)

17) Criteria for the confined ring as follows:
The bubbler ring diameter is assumed to be: **62.875** IN
The number of holes in each ring (per WSDOT dwg): 1,053 holes
(assumes 1"-deducted from length of each half, each end)

18) Bubbler ring hole (orifice) diameter: **0.0625** IN

19) Air flux density required per foot of ring: **32.91** SCFM per FT

20) Max. water depth of rings: **50** FT

21) While the calculations provided in this report are accurate and reflect current industry calculation methods. It must be noted that due to variations in air and water temperatures, variations in barometric pressure and variations of piping and system components used (final dimensions and equipment arrangement), there will be variations in the system performance. On the other hand, these variations should be fairly small and while the actual performance will change based on these variables, the purpose of these calculations is maintained and the system performance will, from a practical point of view, match what is shown in this report.

22) It is assumed that the air flow meters that are installed in each bubbler ring air supply line (located at the manifold) will provide air flow rate information in Standard Cubic Feet per Minute (SCFM) to the system operators. This is per flow meter information provided by WSDOT. As a result, it is further assumed that the operators will adjust air flow throttling valves to achieve the target air flow rates to each air bubble ring as calculated in this set of calculations.

23) It is assumed that all compressed air piping has been selected and fabricated for system pressures up to 300-PSIG.

24) Other assumptions as noted in the body of this set of calculations.

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Bubble Curtain Performance Calculations	Sheet: 7 of: 23

E. CONCLUSION

The performance of the Washington State Colman Dock Bubble Curtain equipment when used as described by this set of calculations should provide the specified air bubble flux required to attenuate pile driving noise.

One air compressor described in the body of the calculations will provide the specified, required flowrate of air required to satisfy the contract specification for water depths to 30-FT deep. Two compressors (operated in parallel with one manifold) will provide the required air for depths to 50-FT deep.

The following detailed calculations indicate that a total air flow rate of 4,186-SCFM is required to supply a depth of 50-FT. The air compressors, set to operate at a discharge pressure of 200-PSIG, will deliver approximately 4,643-SCFM to the bubbler rings.

When used as described here, the expected air bubble flux will be approximately 33-CFM per foot of bubbler ring. The required flux is 33-CFM per foot of ring. ASSUMPTION No. (21) explains some of the unknowns and variables that will affect system performance. It should also be noted that the required air flow rates necessary to achieve this air flux density exceed the compressor ratings by approximately 1%. However, given the variables described, it is nearly impossible to expect the system to perform exactly as described by this set of calculations. It is still expected that the system described in this report will satisfy the intent of the Washington State performance specification.

The final performance of the system will be controlled by the air flow meters and throttling valves provided as part of the system. Operators should adjust the throttling valves to supply 600-SCFM to each bubbler ring - for all depths.

Using the approach described above (with the valves throttled accordingly), the total pressure required in the system is approximately 100-PSIG. The compressors are rated to deliver a maximum output pressure of 200-PSIG.

This flux density and the associated calculations are valid for both the unconfined bubble curtain assembly AND the confined bubble curtain assembly.

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Bubble Curtain Performance Calculations	Sheet: 8 of: 23

E. CONCLUSION

Calculations show that, for the confined bubble curtain arrangement, the 72-IN Dia. HDPE tube must protrude at least 6-IN above the surface of the water so that there will be enough head in the column of water to prevent water from being pumped out of the top of the HDPE tube. This assumes one bubbler ring being used at depth.

Specific attention should be paid to the pipe branch sizes identified in this set of calculations, the hose sizes and the hose lengths. While there is SOME margin in the system (ie. Capacity of equipment vs. system design requirements), longer hoses and smaller piping could quickly result in elimination of this margin.
The sizes shown for hose, valves, pipe and fittings in this set of calculations must be adhered to in order to meet the WSDOT system performance requirements.

It is assumed that the Contractor who will be using this equipment will satisfy the requirements of the specification and any and all safety regulatory requirements for the maintenance and use of this type of equipment.

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F. AIR FLOWRATE REQUIRED FOR BUBBLE CURTAIN

1) Criteria

Required flux density per foot of ring:	32.91	SCFM per FOOT
Total number of bubble curtain rings is:	**7**	- -
Each ring has a nominal diameter of:	68.875	IN
Length of each bubbler pipe is:	18	FT

Using Boyles Law and the depth at each ring, the total free air required is:

Ring No.	Ring Depth (Ft)	Free Air Req'd (SCFM)	Actual Air at depth (ACFM)
1	50.00	593	236
2	43.00	593	257
3	36.00	593	284
4	29.00	593	316
5	22.00	593	356
6	15.00	593	408
7	8.00	593	478
		4,154	2,334

2) Compressor selection -

Manufacturer =	**Doosan**	
Model =	**XHP1170WCAT**	
F.A.D. =	**1,170**	CFM
Rated Operating Pressure =	**200**	PSIG (pressure relief valve set to this)
BHP output =	**540**	HP
Quantity required =	**4**	- -

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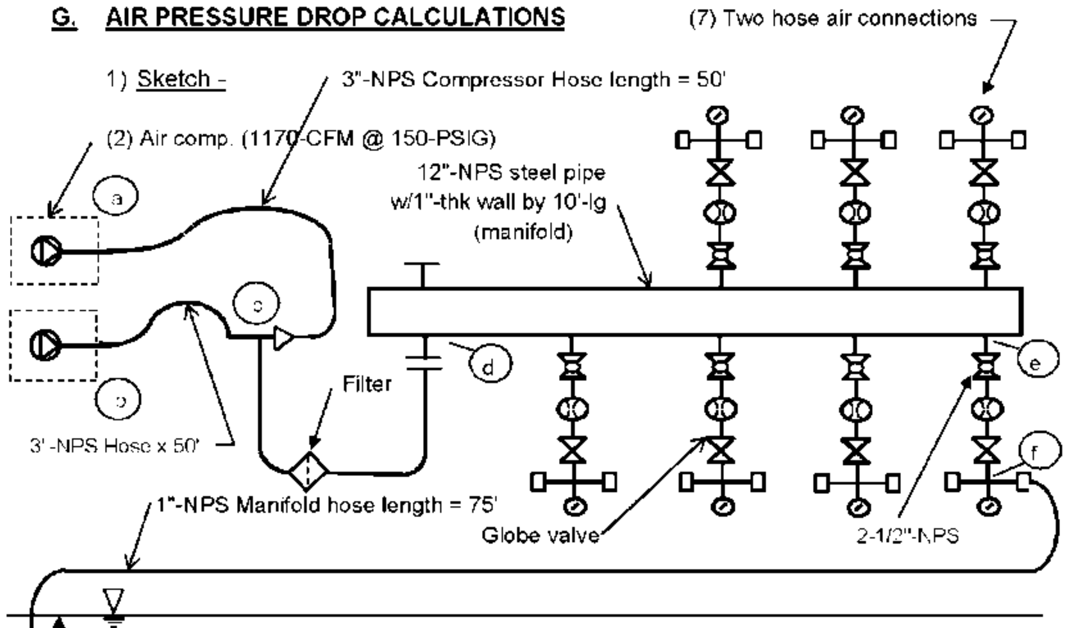
G. AIR PRESSURE DROP CALCULATIONS

1) Sketch -



Branch	Flow Rate	Qty	Description	Unit Eq. Lgth (FT)	Total Eq. Lgth (FT)	Delta P (PSI)
a - c	1,170	50	LF 3"-NPS Rubber hose		50.0	
		1	3"-NPS Tee - branch	15.3	15.3	
b - c	1,170	50	LF 3"-NPS Rubber hose		50.0	
		1	3"-NPS Tee - branch	15.3	15.3	
c - d	1,170	20	LF 3"-NPS Rubber hose		20.0	
		1	Oil Filter (1-1/4"-NPS)			0.7
d - e	2,340	10	LF 12-NPS pipe	10.0	10.0	
e - f	1,170	1	2-1/2"-NPS Ball valve	0.6	0.6	
		1	Flow Meter (2"-NPS RCM, bronze)			5.0
		1	2-1/2"-NPS Globe valve	65.8	65.8	
		1	2-1/2" Tee - branch	11.6	11.6	
	585	1	Reducer 2-1/2" x 1"	15.0	15.0	
f - g	585	75	LF 1"-NPS Hose		75.0	

50

g

Ring

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G. AIR PRESSURE DROP CALCULATIONS

3) Pressure Drop Calculation Summary -

Flowrate out of each compressor = 1170 SCFM
Rated pressure at compressor = 200 PSI

Branch	Size (IN)	Inlet Air Pressure (PSI)	Pipe & Ftg Pressure Loss (PSI)	Other Pressure Loss (PSI)	Total Pressure Loss (PSI)
a - c	**3**	200.00	0.377		0.377
b - c	**3**	200.00	0.377		0.377
c - d	**3**	199.62	0.116		0.116
d - e	**12**	199.51	0.000	**0.700** (filter)	0.700
e - f	**2-1/2**	198.81	1.628	**5.000** (flowmeter) **26.000** (valve)	32.628
f - g	**1**	166.18	14.097		14.097
Ring	**2-1/2**	152.08	**0.700** **(estimated)**		0.700

Delta Z = 50 FT = 21.65 PSIG

NOTE: Adjust throttling valve at manifold until pressure in gauge is: **45** PSIG
This will provide a "ring inlet pressure" at the ring inlet as shown next sheet.
Performance of the bubbler ring with this air pressure shown next sheet.

The total pressure required in the system is: 93.5 PSIG

The compressor output pressure is: 200.0 PSIG

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Bubble Curtain Performance Calculations	Sheet: 12 of: 23

H. AIR RECEIVER STORAGE vs. SYSTEM AIR REQUIREMENTS

1) Discussion -

The manifold shown on the previous sheet acts as an air receiver and, while it doesn't provide a meaningful amount of air storage, it does serve an important function in the system. If it is assumed that the compressor keeps the receiver full as it is operating, this reservoir of pressurized air provides the needed air supply to the hoses that supply pressurized air to the bubbler rings at the required water depths.

The air supply in the receiver is stored at 150-PSIG and is supplied by a constant air flow rate of 1,170-SCFM from the air compressor. The air pressure that is required in the system (supply to the bubbler rings) is required at a lower supply pressure and, as a result, the actual available air in the system is calculated as shown below.

Air supply rate to Receiver	=	1,170	CFM
Air pressure delivered to receiver	=	200	PSIG
Air supply rate required per ring	=	593	CFM
Max Air pressure required to ring	=	93	PSIG (at 50-FT depth)
Available flow rate at required pressure (using Boyle's Law)	=	2,322	CFM per compressor
Available air flowrate (2) compressors	=	4,643	CFM
Total required air flow rate required for seven rings (down to 50-FT)	=	4,154	CFM

Therefore, ONE compressor per pile driving set-up will provide the required air necessary to supply the air bubbler rings at the specified flow rate down to depths of thirty feet of water.

Therefore, TWO compressors per pile driving set-up will provide the required air necessary to supply the air bubbler rings at the specified flow rate down to depths of fifty feet of water.

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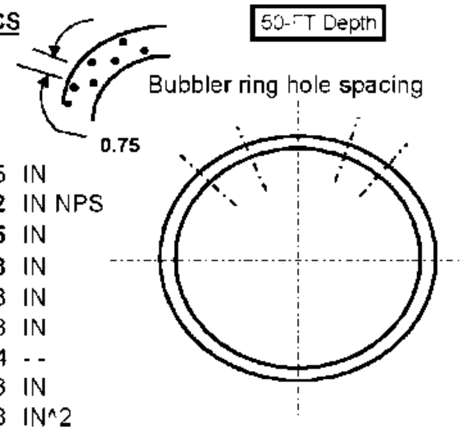
Bubble Curtain Performance Calculations | Sheet: 13 of: 23

I. UNCONFINED RING AIR FLOWRATE CALCS

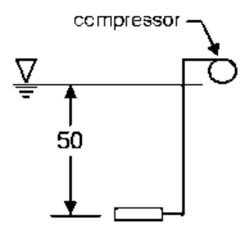
50-FT Depth

(4) holes every 3/4" of length

1) Sketch:



Ring Nom Diameter	=	68.875	IN
Ring Pipe Size	=	**2-1/2**	IN NPS
Pipe OD	=	**2.875**	IN
Pipe ID (Sch 80)	=	**2.323**	IN
Ring OD	=	70.313	IN
Ring OD	=	67.438	IN
No. of Holes in ring	=	1,134	- -
Hole Diameter	=	0.063	IN
Hole Area	=	0.003068	IN^2
Total bubble area in ring	=	3.48	IN^2
	=	0.02	FT^2
Air Temperature	=	60	DEG F
Air Density (atm. pressure)	=	**0.0757**	LBm/FT^3
Air density at (P1), below	=	**0.1919**	LBm/FT^3



2) Flowrate through orifice calculations:

Pressure at ring inlet	=	**22.86**	PSIG
Frictional losses in ring	=	0.69	PSIG (estimated value)
Pressure (P1) at orifice	=	22.2	PSIG
Pressure (P2) at throat	=	21.6	PSIG
Pressure (P3) at outlet	=	21.6	PSIG (water column pressure)
Ratio (P3/P1)	=	0.97	> 0.528
Flow type	=	**Subcritical**	(Greater than critical ratio)
Orifice Discharge Coeff. (C)	=	**0.61**	- - (Sharp edged)
Mass Flow rate thru orifice (W)	=	0.00067	LB / SEC
Volume. flowrate thru orifice	=	0.208	ACFM through each orifice
	=	0.523	SCFM through each orifice

Flow rate through ring	=	593	SCFM
Flow rate per foot of ring	=	32.9	SCFM > 32.91-SCFM

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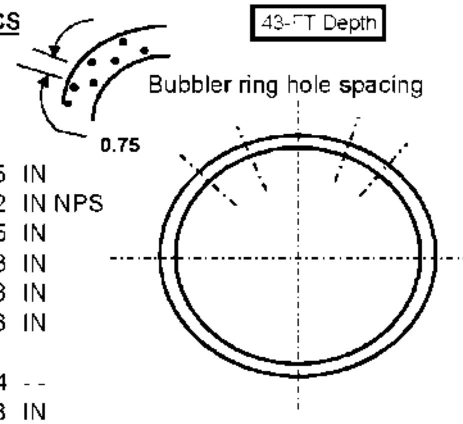
Bubble Curtain Performance Calculations	Sheet: 14 of: 23

I. UNCONFINED RING AIR FLOWRATE CALCS

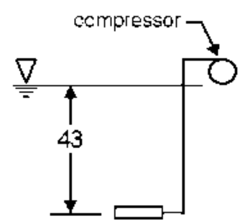
43-FT Depth

(4) holes every 3/4" of length



1) Sketch:

Ring Nom Diameter	=	68.875	IN
Ring Pipe Size	=	2-1/2	IN NPS
Pipe OD	=	2.875	IN
Pipe ID (Sch 80)	=	2.323	IN
Ring OD	=	70.313	IN
Ring OD	=	67.438	IN
No. of Holes in ring	=	1,134	- -
Hole Diameter	=	0.063	IN
Hole Area	=	0.003068	IN^2
Total bubble area in ring	=	3.48	IN^2
	=	0.02	FT^2
Air Temperature	=	60	DEG F
Air Density (atm. pressure)	=	0.0757	LBm/FT^3
Air density at (P1), below	=	**0.1767**	LBm/FT^3



2) Flowrate through orifice calculations:

Pressure at ring inlet	=	**19.76**	PSIG
Frictional losses in ring	=	0.59	PSIG (estimated value)
Pressure (P1) at orifice	=	19.2	PSIG
Pressure (P2) at throat	=	18.6	PSIG
Pressure (P3) at outlet	=	18.6	PSIG (water column pressure)
Ratio (P3/P1)	=	0.97	> 0.528
Flow type	=	**Subcritical**	(Greater than critical ratio)
Orifice Discharge Coeff. (C)	=	**0.61**	- - (Sharp edged)
Mass Flow rate thru orifice (W)	=	0.00067	LB / SEC
Volume. flowrate thru orifice	=	0.227	ACFM through each orifice
	=	0.524	SCFM through each orifice

Flow rate through ring	=	594	SCFM
Flow rate per foot of ring	=	32.9	SCFM > 32.91-SCFM

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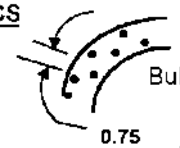
Bubble Curtain Performance Calculations | Sheet: 15 of: 23

I. UNCONFINED RING AIR FLOWRATE CALCS

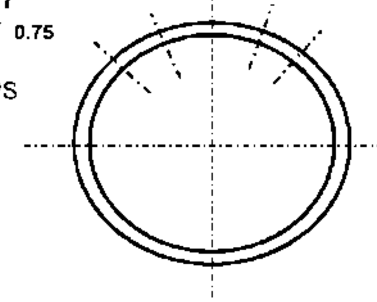
36-FT Depth

(4) holes every 3/4" of length

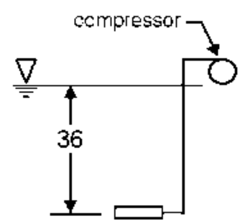


Bubbler ring hole spacing

1) Sketch:



Ring Nom Diameter	=	68.875	IN
Ring Pipe Size	=	2-1/2	IN NPS
Pipe OD	=	2.875	IN
Pipe ID (Sch 80)	=	2.323	IN
Ring OD	=	70.313	IN
Ring OD	=	67.438	IN
No. of Holes in ring	=	1,134	- -
Hole Diameter	=	0.06250	IN
Hole Area	=	0.00307	IN^2
Total bubble area in ring	=	3.47808	IN^2
	=	0.02415	FT^2
Air Temperature	=	60	DEG F
Air Density (atm. pressure)	=	0.07570	LBm/FT^3
Air density at (P1), below	=	**0.15390**	LBm/FT^3



2) Flowrate through orifice calculations:

Pressure at ring inlet	=	**16.65**	PSIG
Frictional losses in ring	=	0.50	PSIG (estimated value)
Pressure (P1) at orifice	=	16.2	PSIG
Pressure (P2) at throat	=	15.6	PSIG
Pressure (P3) at outlet	=	15.6	PSIG (water column pressure)
Ratio (P3/P1)	=	0.97	> 0.528
Flow type	=	**Subcritical**	(Greater than critical ratio)
Orifice Discharge Coeff. (C)	=	**0.61**	- - (Sharp edged)
Mass Flow rate thru orifice (W)	=	0.00064	LB / SEC
Volume. flowrate thru orifice	=	0.251	ACFM through each orifice
	=	0.527	SCFM through each orifice

Flow rate through ring	=	597	SCFM

Flow rate per foot of ring	=	33.1	SCFM > 32.91-SCFM

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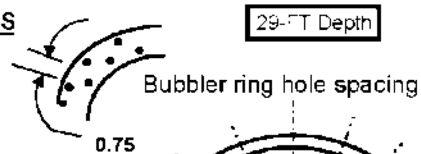
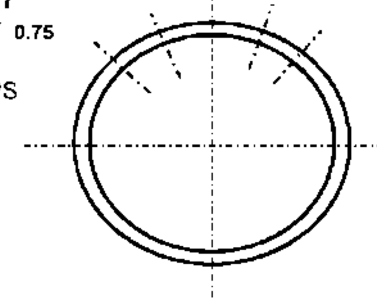
I. UNCONFINED RING AIR FLOWRATE CALCS

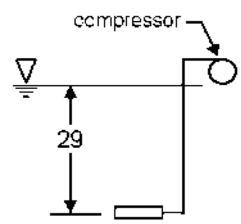


(4) holes every 3/4" of length

1) Sketch:



Ring Nom Diameter	=	68.875	IN
Ring Pipe Size	=	2-1/2	IN NPS
Pipe OD	=	2.875	IN
Pipe ID (Sch 80)	=	2.323	IN
Ring OD	=	70.313	IN
Ring OD	=	67.438	IN
No. of Holes in ring	=	1,134	- -
Hole Diameter	=	0.06250	IN
Hole Area	=	0.00307	IN^2
Total bubble area in ring	=	3.47808	IN^2
	=	0.02415	FT^2
Air Temperature	=	60	DEG F
Air Density (atm. pressure)	=	0.07570	LBm/FT^3
Air density at (P1), below	=	**0.14200**	LBm/FT^3



2) Flowrate through orifice calculations:

Pressure at ring inlet	=	**13.53**	PSIG
Frictional losses in ring	=	0.41	PSIG (estimated value)
Pressure (P1) at orifice	=	13.1	PSIG
Pressure (P2) at throat	=	12.6	PSIG
Pressure (P3) at outlet	=	12.6	PSIG (water column pressure)
Ratio (P3/P1)	=	0.97	> 0.528
Flow type	=	**Subcritical**	(Greater than critical ratio)
Orifice Discharge Coeff. (C)	=	**0.61**	- - (Sharp edged)
Mass Flow rate thru orifice (W)	=	0.00066	LB / SEC
Volume. flowrate thru orifice	=	0.277	ACFM through each orifice
	=	0.524	SCFM through each orifice

Flow rate through ring	=	594	SCFM

Flow rate per foot of ring	=	33.0	SCFM > 32.91-SCFM

Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

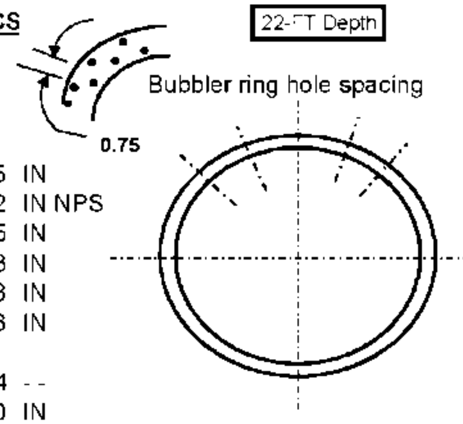
Bubble Curtain Performance Calculations	Sheet: 17 of: 23

I. UNCONFINED RING AIR FLOWRATE CALCS

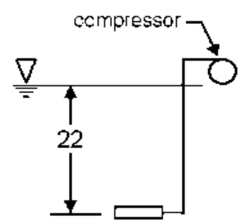
22-FT Depth

(4) holes every 3/4" of length

1) Sketch:



Ring Nom Diameter	=	68.875	IN
Ring Pipe Size	=	2-1/2	IN NPS
Pipe OD	=	2.875	IN
Pipe ID (Sch 80)	=	2.323	IN
Ring OD	=	70.313	IN
Ring OD	=	67.438	IN
No. of Holes in ring	=	1,134	- -
Hole Diameter	=	0.06250	IN
Hole Area	=	0.00307	IN^2
Total bubble area in ring	=	3.47808	IN^2
	=	0.02415	FT^2
Air Temperature	=	60	DEG F
Air Density (atm. pressure)	=	0.07570	LBm/FT^3
Air density at (P1), below	=	**0.12830**	LBm/FT^3



2) Flowrate through orifice calculations:

Pressure at ring inlet	=	**10.40**	PSIG
Frictional losses in ring	=	0.31	PSIG (estimated value)
Pressure (P1) at orifice	=	10.1	PSIG
Pressure (P2) at throat	=	9.5	PSIG
Pressure (P3) at outlet	=	9.5	PSIG (water column pressure)
Ratio (P3/P1)	=	0.97	> 0.528
Flow type	=	**Subcritical**	(Greater than critical ratio)
Orifice Discharge Coeff. (C)	=	**0.61**	- - (Sharp edged)
Mass Flow rate thru orifice (W)	=	0.00067	LB / SEC
Volume. flowrate thru orifice	=	0.313	ACFM through each orifice
	=	0.528	SCFM through each orifice

Flow rate through ring	=	599	SCFM

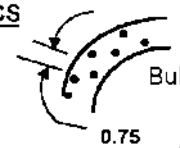
Flow rate per foot of ring	=	33.2	SCFM > 32.91-SCFM

Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

Bubble Curtain Performance Calculations	Sheet: 18 of: 23

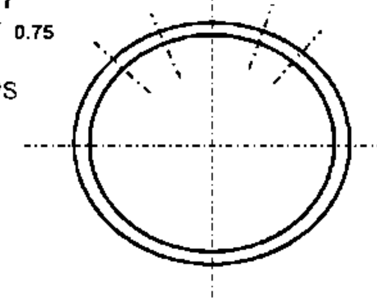
I. UNCONFINED RING AIR FLOWRATE CALCS

15-FT Depth

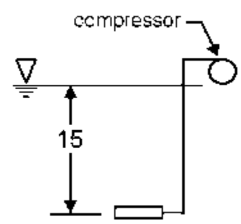


(4) holes every 3/4" of length

1) Sketch:



Ring Nom Diameter	=	68.875	IN
Ring Pipe Size	=	2-1/2	IN NPS
Pipe OD	=	2.875	IN
Pipe ID (Sch 80)	=	2.323	IN
Ring OD	=	70.313	IN
Ring OD	=	67.438	IN
No. of Holes in ring	=	1,134	- -
Hole Diameter	=	0.06250	IN
Hole Area	=	0.00307	IN^2
Total bubble area in ring	=	3.47808	IN^2
	=	0.02415	FT^2
Air Temperature	=	60	DEG F
Air Density (atm. pressure)	=	0.07570	LBm/FT^3
Air density at (P1), below	=	**0.15390**	LBm/FT^3



2) Flowrate through orifice calculations:

Pressure at ring inlet	=	**7.23**	PSIG
Frictional losses in ring	=	0.22	PSIG (estimated value)
Pressure (P1) at orifice	=	7.0	PSIG
Pressure (P2) at throat	=	6.5	PSIG
Pressure (P3) at outlet	=	6.5	PSIG (water column pressure)
Ratio (P3/P1)	=	0.97	> 0.528
Flow type	=	**Subcritical**	(Greater than critical ratio)
Orifice Discharge Coeff. (C)	=	**0.61**	- - (Sharp edged)
Mass Flow rate thru orifice (W)	=	0.00092	LB / SEC
Volume. flowrate thru orifice	=	0.357	ACFM through each orifice
	=	0.527	SCFM through each orifice

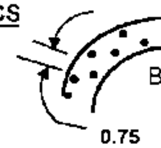
Flow rate through ring	=	598	SCFM
Flow rate per foot of ring	=	33.1	SCFM > 32.91-SCFM

Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

Bubble Curtain Performance Calculations	Sheet: 19 of: 23

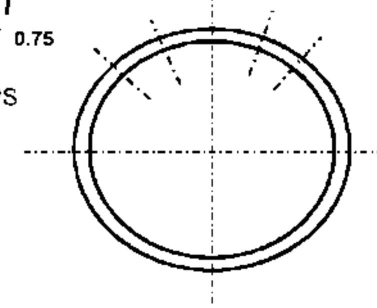
I. UNCONFINED RING AIR FLOWRATE CALCS

8-FT Depth

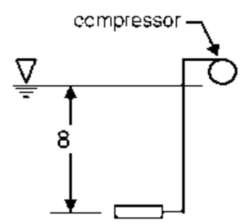


(4) holes every 3/4" of length

1) Sketch:



Ring Nom Diameter	=	68.875	IN
Ring Pipe Size	=	2-1/2	IN NPS
Pipe OD	=	2.875	IN
Pipe ID (Sch 80)	=	2.323	IN
Ring OD	=	70.313	IN
Ring OD	=	67.438	IN
No. of Holes in ring	=	1,134	- -
Hole Diameter	=	0.06250	IN
Hole Area	=	0.00307	IN^2
Total bubble area in ring	=	3.47808	IN^2
	=	0.02415	FT^2
Air Temperature	=	60	DEG F
Air Density (atm. pressure)	=	0.07570	LBm/FT^3
Air density at (P1), below	=	0.15390	LBm/FT^3



2) Flowrate through orifice calculations:

Pressure at ring inlet	=	**3.99**	PSIG
Frictional losses in ring	=	0.12	PSIG (estimated value)
Pressure (P1) at orifice	=	3.9	PSIG
Pressure (P2) at throat	=	3.5	PSIG
Pressure (P3) at outlet	=	3.5	PSIG (water column pressure)
Ratio (P3/P1)	=	0.97	> 0.528
Flow type	=	**Subcritical**	(Greater than critical ratio)
Orifice Discharge Coeff. (C)	=	**0.61**	- - (Sharp edged)
Mass Flow rate thru orifice (W)	=	0.00107	LB / SEC
Volume. flowrate thru orifice	=	0.417	ACFM through each orifice
	=	0.527	SCFM through each orifice

Flow rate through ring	=	598	SCFM

Flow rate per foot of ring	=	33.2	SCFM > 32.91-SCFM

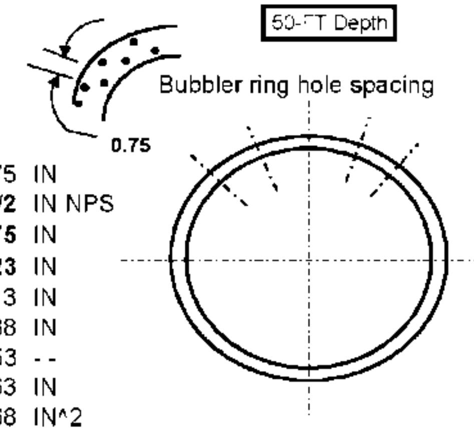
Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

Bubble Curtain Performance Calculations | Sheet: 20 of: 23

J. CONFINED RING AIR FLOWRATE CALCS

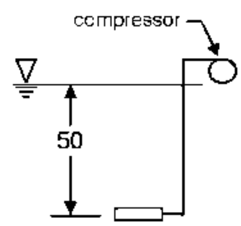
50-FT Depth

(4) holes every 3/4" of length



1) Sketch:

Ring Nom Diameter	=	62.875	IN
Ring Pipe Size	=	**2-1/2**	IN NPS
Pipe OD	=	**2.875**	IN
Pipe ID (Sch 80)	=	**2.323**	IN
Ring OD	=	64.313	IN
Ring OD	=	61.438	IN
No. of Holes in ring	=	1,053	- -
Hole Diameter	=	0.063	IN
Hole Area	=	0.003068	IN^2
Total bubble area in ring	=	3.23	IN^2
	=	0.02	FT^2
Air Temperature	=	60	DEG F
Air Density (atm. pressure)	=	**0.0757**	LBm/FT^3
Air density at (P1), below	=	**0.1919**	LBm/FT^3



2) Flowrate through orifice calculations:

Pressure at ring inlet	=	**22.86**	PSIG
Frictional losses in ring	=	0.69	PSIG (estimated value)
Pressure (P1) at orifice	=	22.2	PSIG
Pressure (P2) at throat	=	21.6	PSIG
Pressure (P3) at outlet	=	21.6	PSIG (water column pressure)
Ratio (P3/P1)	=	1.59	> 0.528
Flow type	=	**Subcritical**	(Greater than critical ratio)
Orifice Discharge Coeff. (C)	=	**0.61**	- - (Sharp edged)
Mass Flow rate thru orifice (W)	=	0.00067	LB / SEC
Volume. flowrate thru orifice	=	0.208	ACFM through each orifice
	=	0.523	SCFM through each orifice

Flow rate through ring	=	551	SCFM

Flow rate per foot of ring	=	33.5	SCFM > 32.91-SCFM

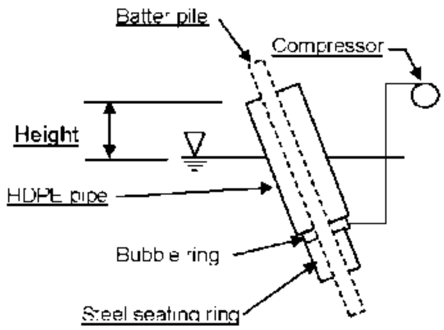
Project: **Colman Dock Project** | By: jwk | Date: 14-Sep-**17** **REV B**

Bubble Curtain Performance Calculations	Sheet: 21 of: 23

J. CONFINED RING AIR PUMP EFFECT (HDPE TUBE LENGTH CALC)

1) Discussion

The confined bubble curtain arrangement is shown in simplified sketch below.



The confined bubble curtain arrangement will differ from the unconfined assembly in two ways: 1) The ring diameter is slightly smaller, and 2) There will only be (1) bubbler ring used in the assembly rather than (7). The (1) ring will be placed at the bottom of an external HDPE tube (shown above) that will be positioned over the batter pile (driven at an angle as shown). The air will be supplied to the ring and the result will be that the air and water will mix within the HDPE tube to create the air barrier needed to attenuate the noise during pile driving.

The calculation that follows, however, is necessary to verify that the confined arrangement will not result in a "pumping action" of the water inside of the HDPE tube that is positioned around the batter pile to the extent that the water in the confinement tube is displaced by the air bubbles emitting from the ring.
The tube height above the water surface will be determined by using the required air volume (in the bubble curtain rings) and from this, will determine the static head that the air can "lift". This "lift" height will define the height above water surface that the HDPE pipe must extend.

If the height of the tube above the waterline is adequate to limit the flow of water out of the tube, the arrangement will be considered acceptable.

Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

Bubble Curtain Performance Calculations	Sheet: 22 of: 23

J. CONFINED RING AIR PUMP EFFECT (HDPE TUBE LENGTH CALC)

2) Behavior of air & water in confinement tube

a) Assume, in the worst case, that the water depth for the batter being driven is 50-FT of water. This means that the amount of air in the HDPE confinement tube will be at a maximum due to the requirement at this depth for the (1) bubbler ring that delivering the required amount of air.

b) Also assume that this set of calculations is based on air having a density at the midpoint depth (ie. 25-FT deep). This means that the air between 25-FT and 50-FT will be more compressed due to the water column (ie. air more dense) and that the air between 25-FT and the surface will have a lower density (due to less static head acting on the air. The two should average out to be close to the actual conditions over the entire water column height of 50-FT. Assumed air density is: **0.1326** LB/FT^3

c) The assumed density of the seawater over the range of the 50-FT depth is assumed to be $64.2\text{-}LB/FT^3$.

d) Steady state volume of air in tube

Air out of each orifice at 25-FT depth	=	**0.296**	ACFM	(use this value)
		0.526	SCFM	
Orifice count per ring	=	1,053	- -	
Total ring count	=	**1**	- -	
Total air flow into confined pipe	=	551	CFM	
Assumed OD of HDPE tube	=	**72**	IN	
HDPE wall thickness	=	**1.375**	IN	
Assumed HDPE tube ID	=	69.25	IN	
Assumed length of HDPE tube	=	**55**	FT	
Total volume of HDPE tube	=	1,439	FT^3	

Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

Bubble Curtain Performance Calculations	Sheet: 23 of: 23

J. CONFINED RING AIR PUMP EFFECT (HDPE TUBE LENGTH CALC)

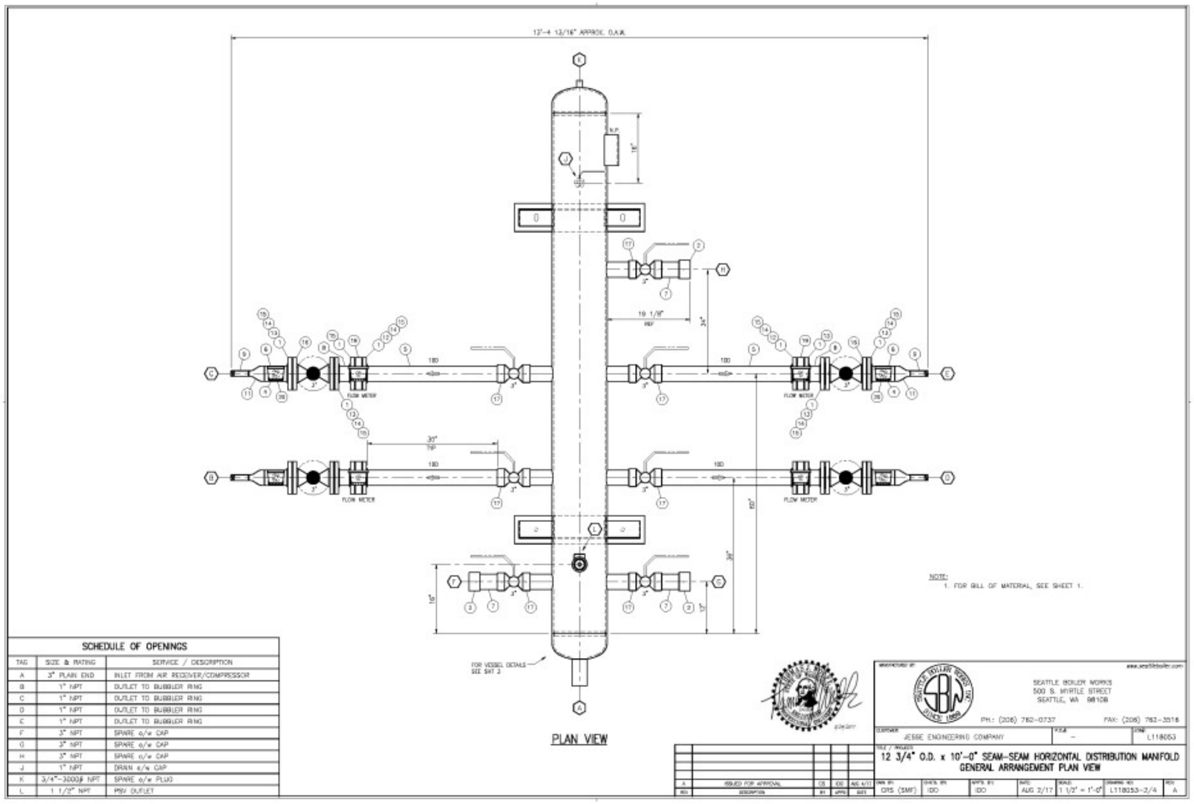
3) Behavior of air & water in confinement tube — 72"-DIA.

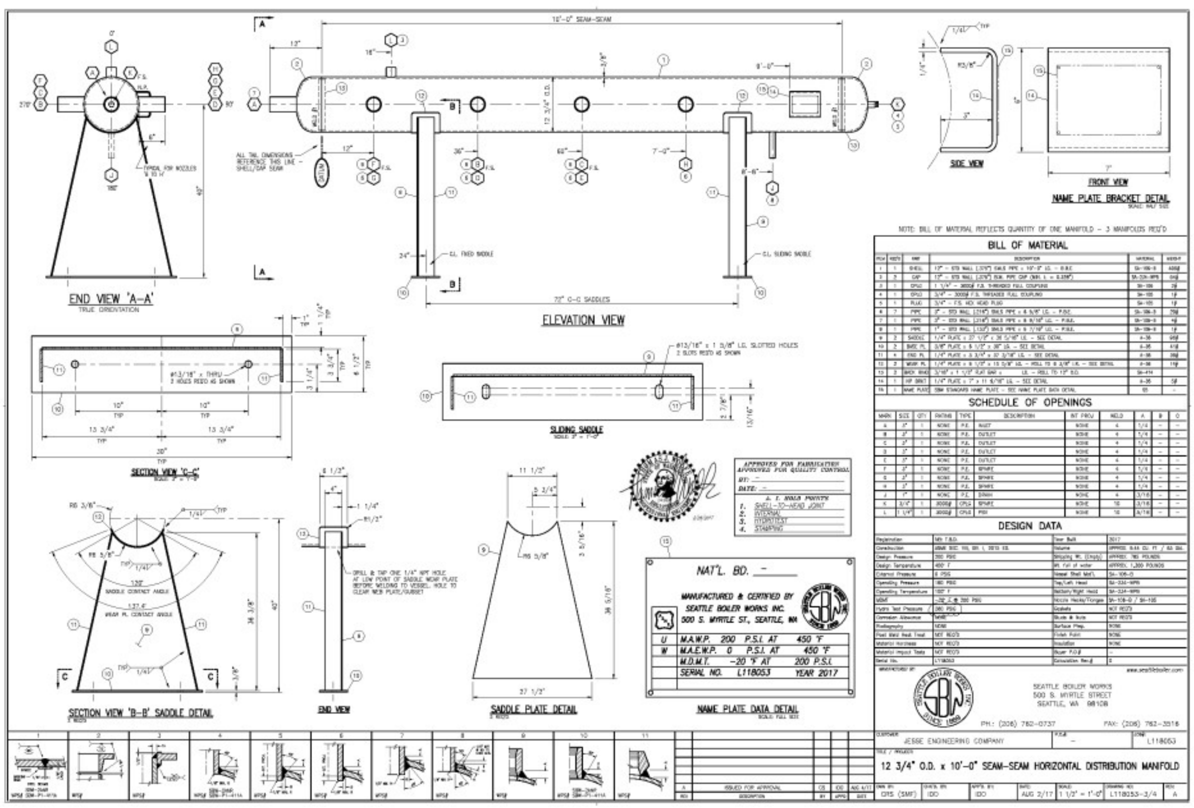
Pumping rate	=	**0.01**	GAL/DAY
Pipe diameter	=	**72.00**	IN
Submergence	=	**50.0**	FT
Lift	=	**0.5**	FT
cross-sectional area of pipe	=	28.274	FT^2
Pipe volume	=	1,427.85	FT^3
Pipe volume	=	7.48	GAL/FT^3
Vl (Flow rate)	=	0	GPM
A (Pipe area)	=	28.274	FT^2
L (Lift)	=	0.5	FT
D (Pipe diameter)	=	72	IN
Lf (density of fluid)	=	**64.2**	LBm/FT^3
S (submergence)	=	50.00	FT
Lg (Gas density)	=	**0.0765**	LBm/FT^3
Vg (Gas flow)	=	709	CFM
Actual flowrate out of (1) ring	=	551	CFM
Pressure	=	21.89	PSI

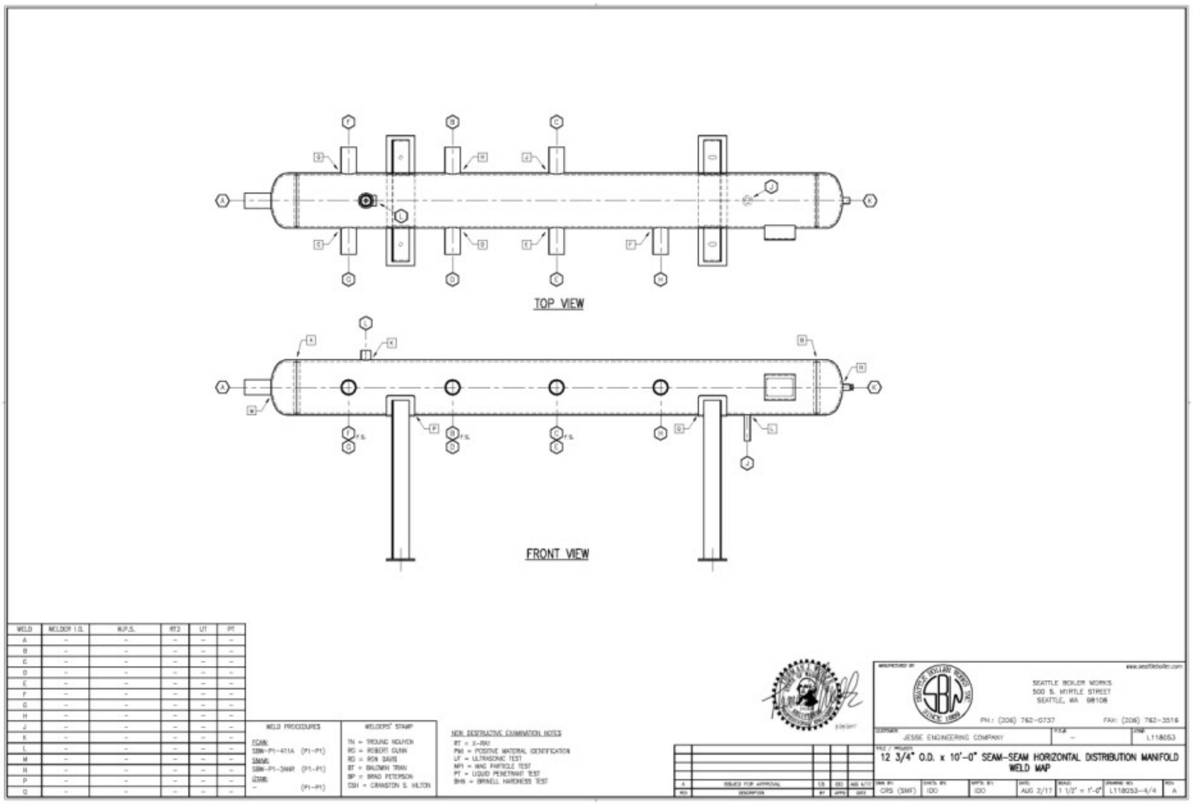
NOTE: This calculation shows that at a flowrate of 709-CFM and a tube length extending 0.5-FT (6-IN) MINIMUM above the surface, water will begin pumping out of the top of the HDPE tube.

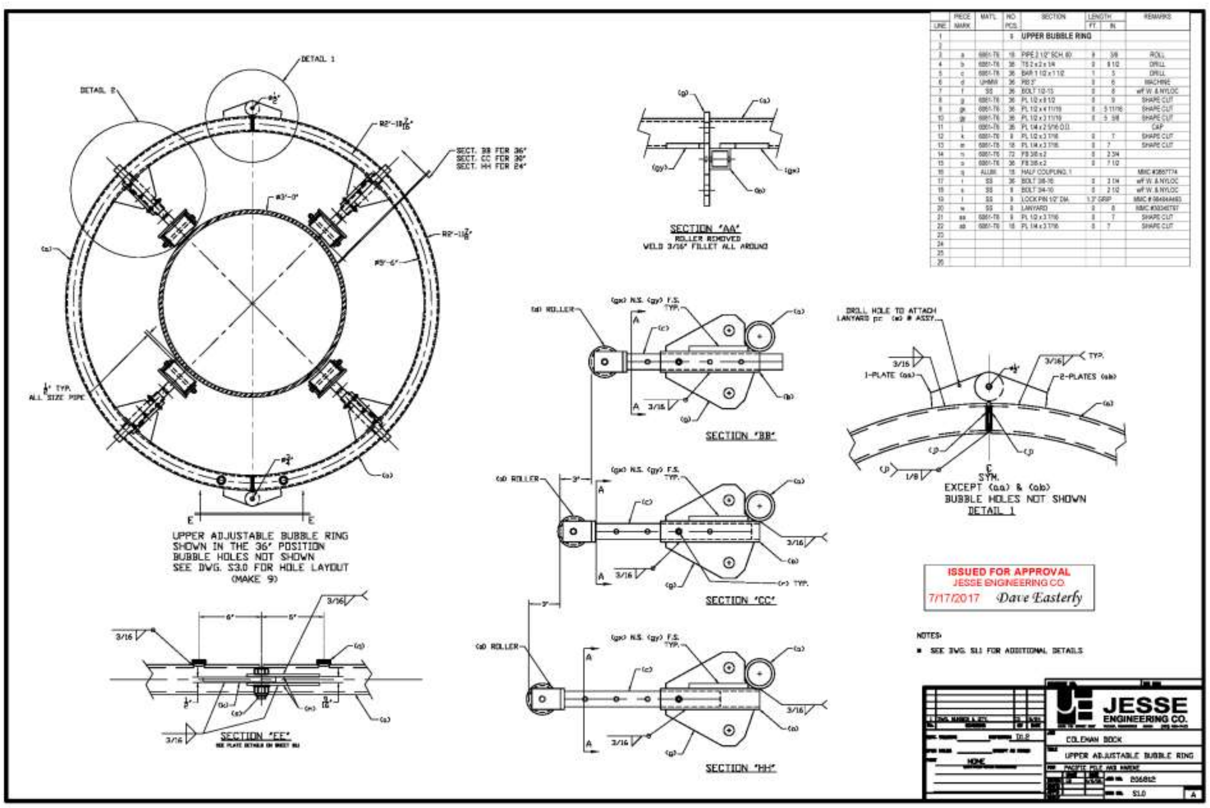
For the required air flowrate of 551-CFM (calculated in earlier calc.) the water will stay in the tube.

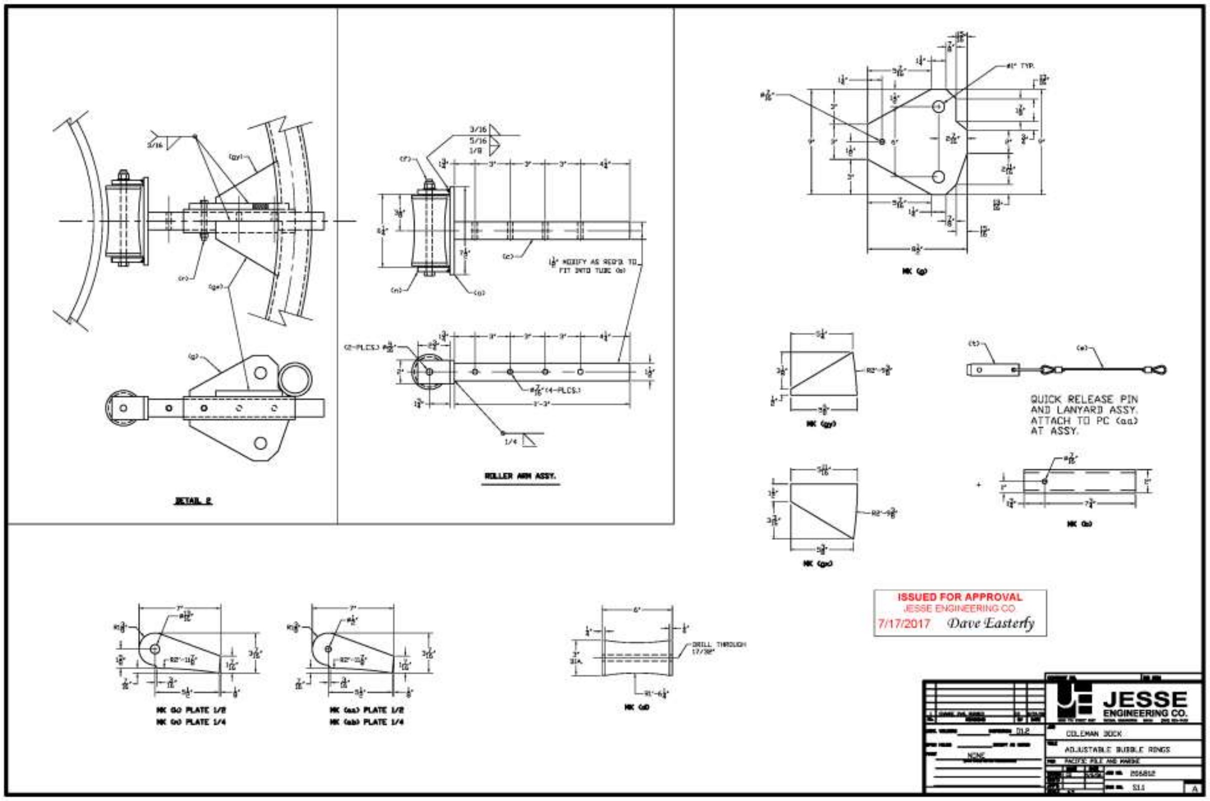
Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

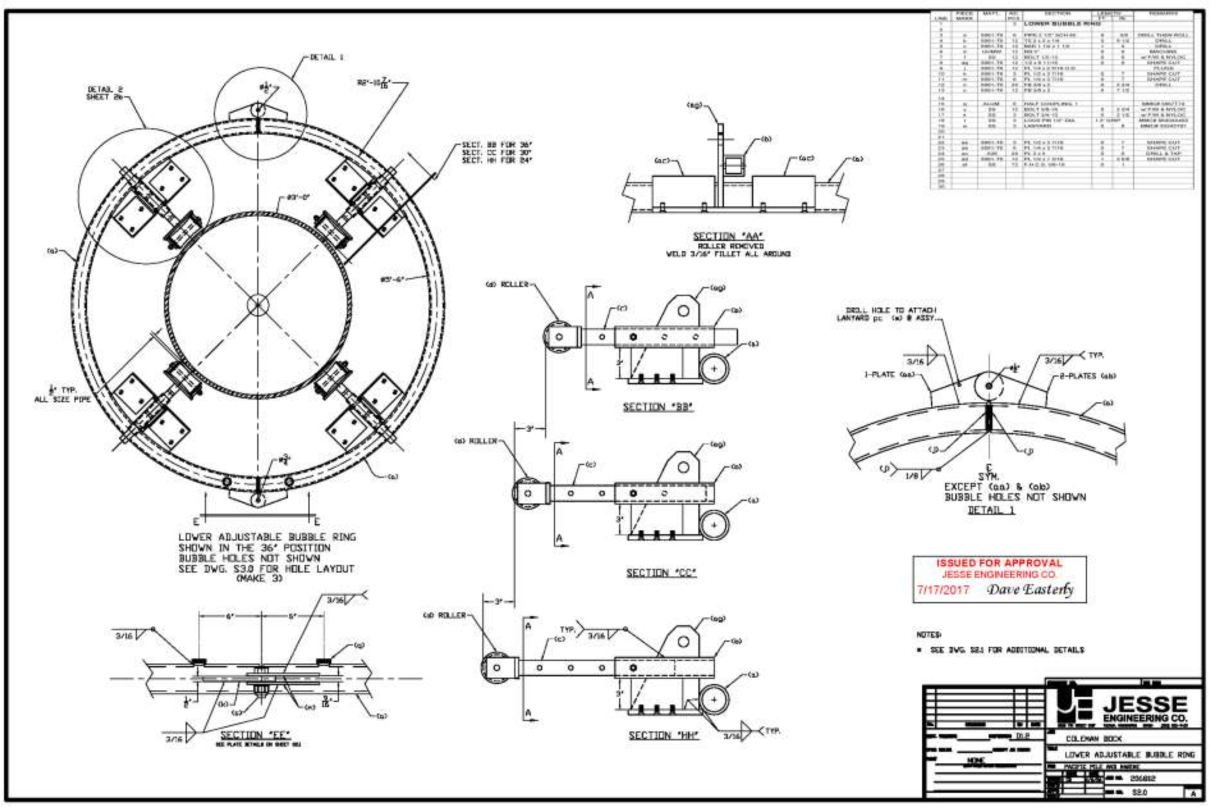

PLAN VIEW
SCHEDULE OF OPENINGS
SEATTLE BOILER WORKS
500 S. MYRTLE STREET
SEATTLE, WA 98108
JESSE ENGINEERING COMPANY
12 3/4" O.D. x 10'-0" SEAM-SEAM HORIZONTAL DISTRIBUTION MANIFOLD
GENERAL ARRANGEMENT PLAN VIEW

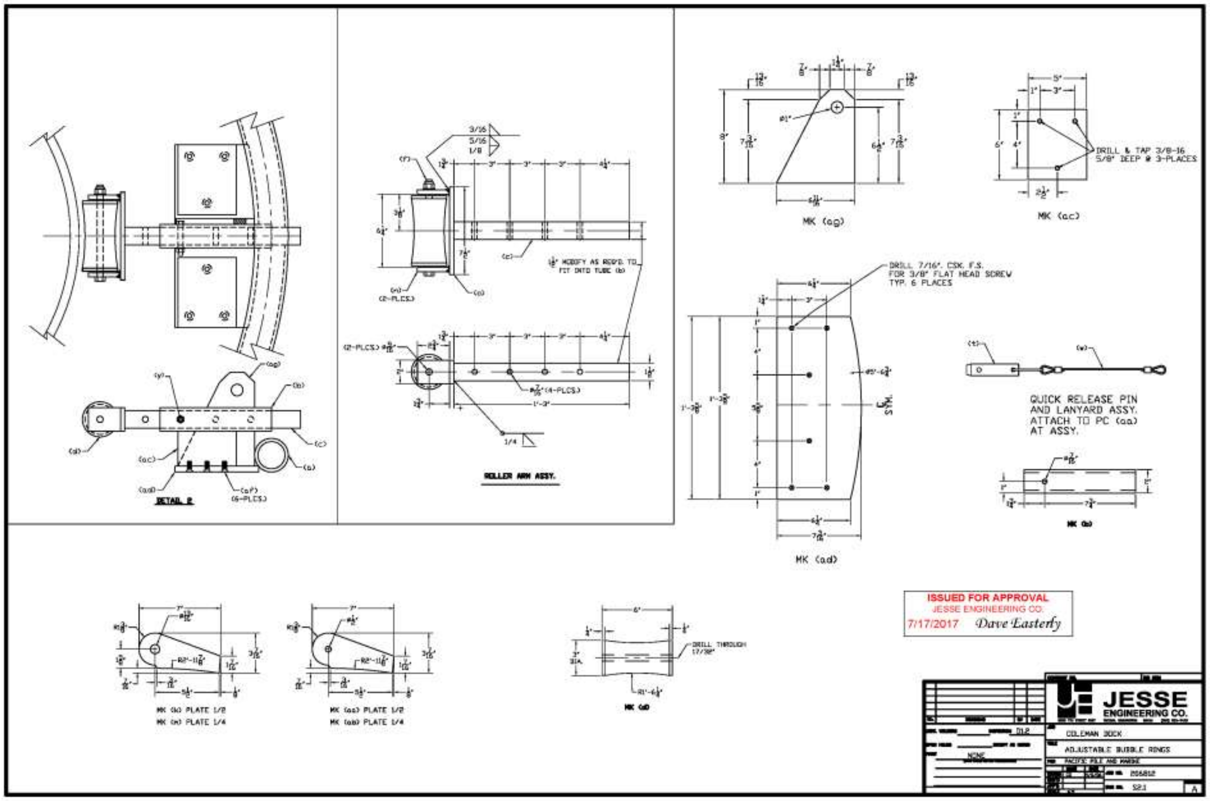

END VIEW 'A-A'
ELEVATION VIEW
SIDE VIEW
FRONT VIEW
NAME PLATE BRACKET DETAIL
BILL OF MATERIAL
SCHEDULE OF OPENINGS
DESIGN DATA
SLIDING SADDLE
SECTION VIEW 'C-C'
SECTION VIEW 'B-B' SADDLE DETAIL
END VIEW
SADDLE PLATE DETAIL
NAME PLATE DATA DETAIL
SEATTLE BOILER WORKS
500 S. MYRTLE STREET
SEATTLE, WA 98108
JESSE ENGINEERING COMPANY
12 3/4" O.D. x 10'-0" SEAM-SEAM HORIZONTAL DISTRIBUTION MANIFOLD

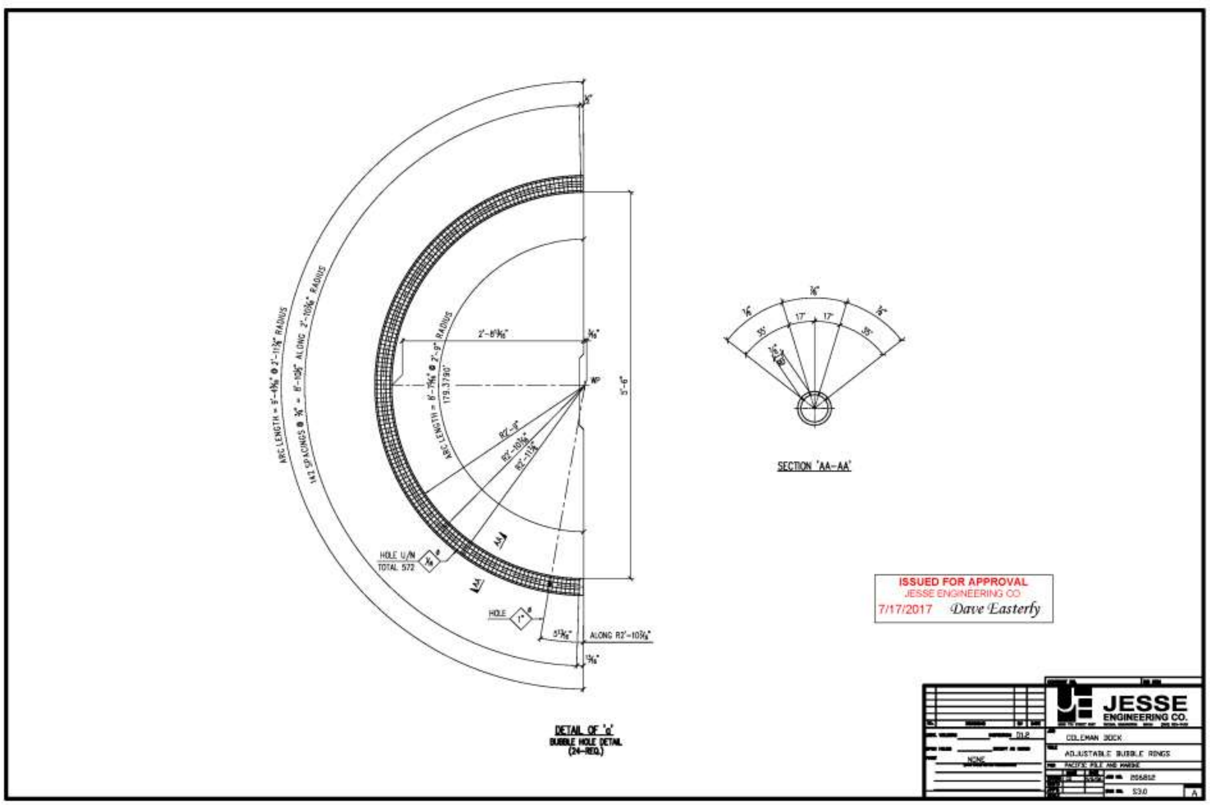

TOP VIEW
FRONT VIEW
SEATTLE BOILER WORKS
500 S. MYRTLE STREET
SEATTLE, WA 98108
JESSE ENGINEERING COMPANY
12 3/4" O.D. x 10'-0" SEAM-SEAM HORIZONTAL DISTRIBUTION MANIFOLD
WELD MAP


DETAIL 1
DETAIL 2
SECTION "AA"
ROLLER REMOVED
WELD 3/16" FILLET ALL AROUND
UPPER ADJUSTABLE BUBBLE RING
SHOWN IN THE 36" POSITION
BUBBLE HOLES NOT SHOWN
SEE DWG. S3.0 FOR HOLE LAYOUT
(MAKE 9)
SECTION "BB"
SECTION "CC"
SECTION "EE"
SECTION "HH"
EXCEPT (aa) & (ab)
BUBBLE HOLES NOT SHOWN
DETAIL 1
ISSUED FOR APPROVAL
JESSE ENGINEERING CO.
7/17/2017 Dave Easterly
NOTES:
SEE DWG. S1.1 FOR ADDITIONAL DETAILS
JESSE
ENGINEERING CO.
UPPER ADJUSTABLE BUBBLE RING


DETAIL 2
ROLLER ARM ASSY.
QUICK RELEASE PIN
AND LANYARD ASSY.
ATTACH TO PC (aa)
AT ASSY.
ISSUED FOR APPROVAL
JESSE ENGINEERING CO.
7/17/2017 Dave Easterly
JESSE
ENGINEERING CO.
COLEMAN DOCK
ADJUSTABLE BUBBLE RINGS
PACIFIC PILE AND MARINE
206852
S11


DETAIL 1
DETAIL 2
SHEET 26
SECT. BB FOR 36"
SECT. CC FOR 30"
SECT. HH FOR 24"
SECTION "AA"
ROLLER REMOVED
WELD 3/16" FILLET ALL AROUND
SECTION "BB"
SECTION "CC"
SECTION "HH"
SECTION "EE"
LOWER ADJUSTABLE BUBBLE RING
SHOWN IN THE 36" POSITION
BUBBLE HOLES NOT SHOWN
SEE DWG. S3.0 FOR HOLE LAYOUT
(MAKE 3)
EXCEPT (aa) & (ab)
BUBBLE HOLES NOT SHOWN
ISSUED FOR APPROVAL
JESSE ENGINEERING CO.
7/17/2017 Dave Easterly
NOTES:
SEE DWG. S2.1 FOR ADDITIONAL DETAILS
JESSE
ENGINEERING CO.
COLEMAN DOCK
LOWER ADJUSTABLE BUBBLE RING
PACIFIC PILE AND MARINE
206852
S2.0


ROLLER ARM ASSY.
DETAIL 2
MK (ag)
MK (ac)
DRILL & TAP 3/8-16 5/8" DEEP @ 3-PLACES
DRILL 7/16", CSK. F.S. FOR 3/8" FLAT HEAD SCREW TYP. 6 PLACES
MK (ad)
QUICK RELEASE PIN AND LANYARD ASSY. ATTACH TO PC (aa) AT ASSY.
ISSUED FOR APPROVAL
JESSE ENGINEERING CO.
7/17/2017 Dave Easterly
JESSE ENGINEERING CO.
COLEMAN DOCK
ADJUSTABLE BUBBLE RINGS
PACIFIC PILE AND MARINE


SECTION 'AA-AA'
ISSUED FOR APPROVAL
JESSE ENGINEERING CO.
7/17/2017 Dave Easterly
DETAIL OF 'a'
BUBBLE HOLE DETAIL
(24-REQ.)
JESSE ENGINEERING CO.
COLEMAN DOCK
ADJUSTABLE BUBBLE RINGS
PACIFIC PILE AND MARINE