Pacific Pile & Marine

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TRANSMITTAL

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

DATE: 5/16/2019

RE: Phase 2 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 21.6 – Phase 2 Hydroacoustic Monitoring Final Report – General Conditons. 1-07.6(6)
1	Phase 2 Hydroacoustic Monitoring Fina Report

THESE ITEMS ARE TRANSMITTED AS CHECKED BELOW:

- [x] For approval. Please return 1 copy with approval and any correction notations.
- [ ] Revised & for final approval. Please return _____ copies.
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- [ ] Resubmit ______ Copies For Approval.
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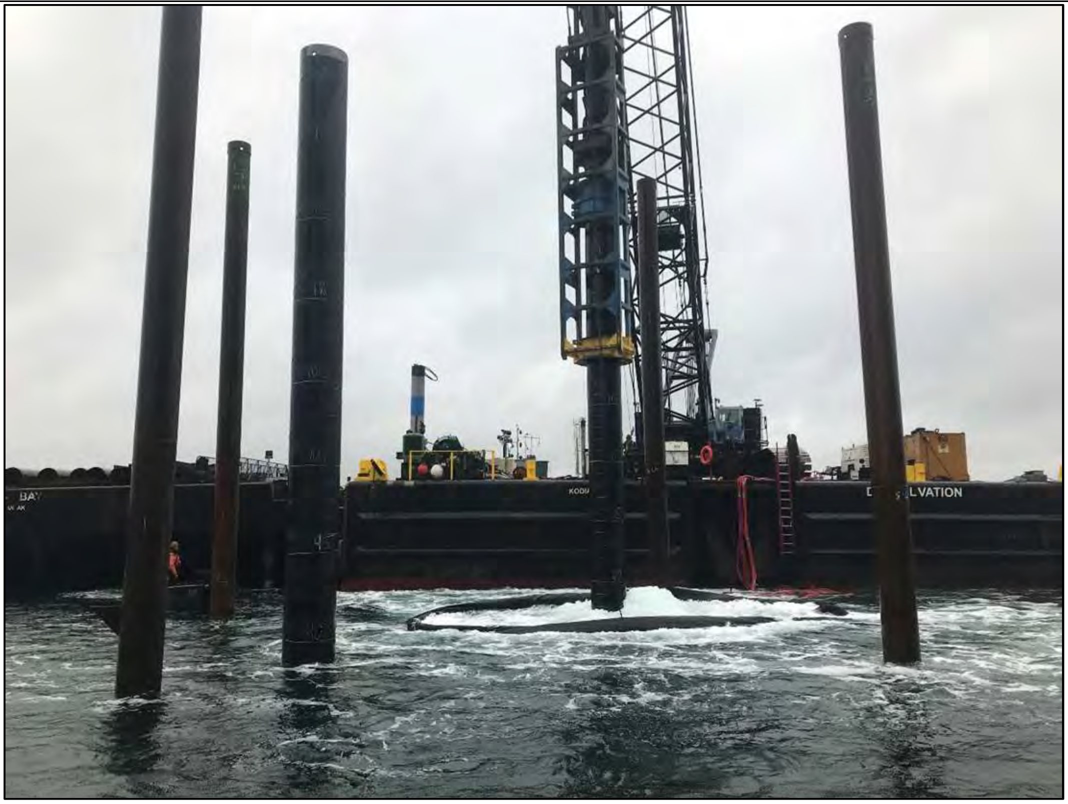
REMARKS:

Copy To:

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.

05/17/2019 — Date
087.4 - 1-07.6 — Submittal #
Brandon Brody-Heim — Reviewed By

Sincerely,
PACIFIC PILE & MARINE, L.P.



COLMAN DOCK SEASON 2
HYDROACOUSTIC MONITORING REPORT

May 14, 2019

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 Technical Report presents the results of underwater sound level measurements made between October 2018 and January 2019 during the installation of 24-inch and 36-inch steel pipe piles driven with a diesel impact hammer. This monitoring was conducted during Season 2 of the Seattle Multimodal Terminal at Colman Dock ("Project").

Average underwater 90% RMS (RMS_{90}) sound levels measured approximately 33 feet (10 meters) from impact pile driving ranged between 162 and 179 dB re: 1 μPa for the 24-inch diameter piles driven for the Temporary Work Trestle and 172 and 193 dB re: 1 μPa for the 36-inch diameter piles driven at the North Trestle, Passenger Only Ferry Floats, and South Notch. Average peak sound levels measured during the installation of the 24-inch diameter piles ranged between 178 and 190 dB re: 1 μPa and 187 and 204 dB re: 1 μPa for 36-inch diameter piles.

Based on the highest average broadband RMS_{90} sound levels measured by the far-field hydrophone, the distance required for underwater sound levels to reach the marine mammal detection (Level B) threshold of 160 dB re: 1 μPa was estimated to be 3,341 feet. The distance required to reach the 180 dB re: 1 μPa injury threshold (Level A) for cetaceans was calculated to be 155 feet and 33 feet for pinnipeds.

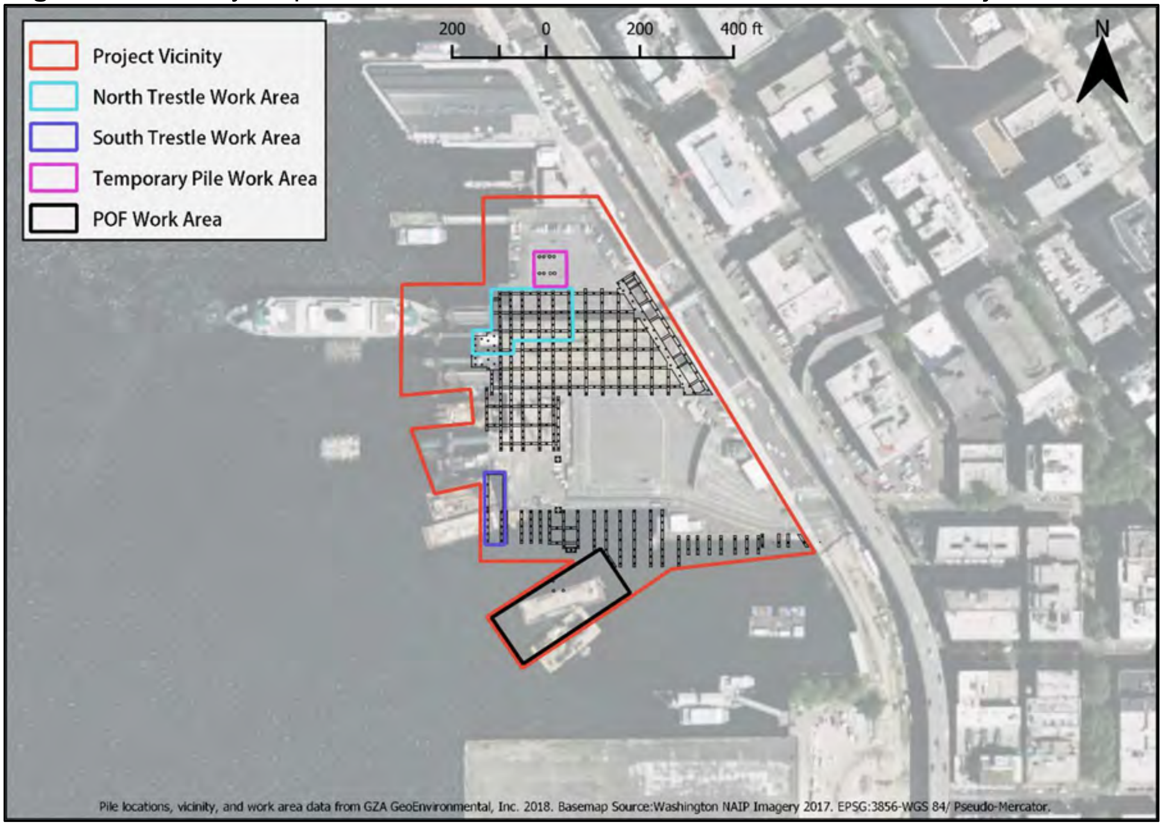
2.0 INTRODUCTION

This Hydroacoustic Monitoring Report presents the results of underwater sound levels measured during the installation of 24-inch and 36-inch steel pipe piles with a diesel impact hammer during Season 2 (2018/2019 in-water work window) of the Seattle Multimodal Terminal at Colman Dock Project ("Project").

The Project Specifications and the Underwater Noise Monitoring Plan issued by the Washington State Department of Transportation (WSDOT), dated July 27, 2016 includes requirements for hydroacoustic monitoring. These requirements include 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. 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 sound level measurements were conducted between October 2018 and January 2019.

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:

- **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).

- **Root Mean Square (RMS)**

  The RMS level is the square root of the average squared pressure over a given time period. For vibratory pile driving RMS levels are calculated over 10 second periods. 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 2 Underwater Noise Monitoring Plan issued by The Greenbusch Group, Inc. dated October 25, 2018. 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.

4.3 Greenbusch Underwater Noise Monitoring Plan

The Colman Dock Phase 2 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 2, all steel pipe piles were initially driven with a vibratory hammer and proofed using a diesel impact hammer. The piles for the Temporary Work Trestle are 24-inch steel pipe piles with wall thicknesses of ½-inch. North Trestle, Passenger Only Ferry Float, and South Notch piles are 36-inch steel pipe piles and are approximately 90-feet long. All piles except for the Temporary Work Trestle piles have a wall thickness of one inch. The substrate is primarily composed of sand, shell hash, silt and includes some gravel and cobble.

The piles for the Temporary Work Trestle were driven with an ICE I-100V2 diesel impact hammer. The ICE I-100 V2 has a maximum energy rating of 330,760 foot-pounds, a ram weight of 22,050 pounds and a stroke length of 11.81 feet. Specifications for the ICE I-100V2 are shown in the Appendix.

All other piles installed during hydroacoustic monitoring were driven using a Delmag 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 Delmag D100-52 diesel impact hammer can be found in the Appendix of this Report.

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

Table 5.1 Summary Pipe Piles, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Embedment[1]	Number of Strikes[2]
Temporary Work Trestle						
Pile 2	10/21/18	Bubble Curtain	130	14	69	178
Pile 3			150	20	63	126
North Trestle						
N12.5-NJ	12/7/18	Bubble Curtain	210	27	58	272
N11-NG	1/10/19		210	25	57	401
N11.5-NG			220	24	48	136
Passenger Only Ferry Floats						
POF-E	12/11/18	Bubble Curtain	500	47	43	43
POF-D			520	47	43	54
POF-F			485	46	36	72
South Notch						
S26-SG	12/14/18	Bubble Curtain	505	40	37	181
S26-SF.3			510	42	35	139
S26-SE.5			515	44	33	161

1. North Trestle and Passenger Only Ferry Float embedment depth listed on pile logs. South Notch embedment was estimated from water depth and minimum tip elevations listed on pile schedule. Temporary Work Trestle embedment estimated from water depth and minimum top elevations shown on plans.
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 5.1 and Figure 5.2. The system design calculations and drawings of the bubble curtain are provided in the Appendix.

Figure 5.1 Bubble Curtain

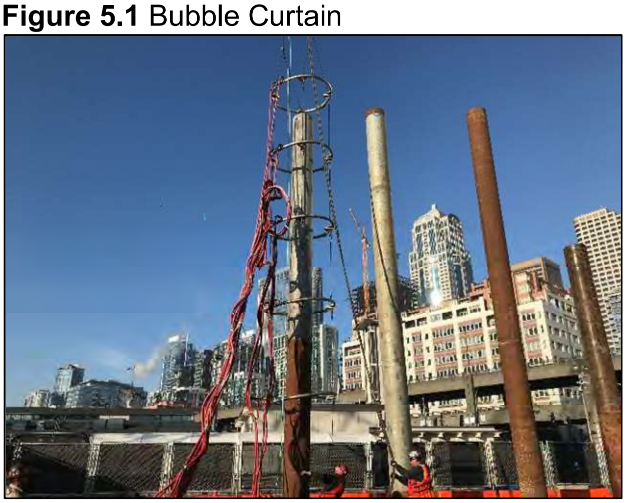


Figure 5.2 Operating Bubble Curtain

6.0 MEASUREMENT METHODOLOGY

6.1 Equipment

The hydroacoustic monitoring equipment used during Season 2 is identified in Table 6.1.

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

Hydroacoustic 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.

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. A photo of the hydroacoustic monitoring equipment is provided Figure 6.1.

Figure 6.1 Hydroacoustic 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 the pile.

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, boats, 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 6.2 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 6.2 Hydrophone Location Summary, Feet

Pile ID	Hydrophone	Depth at Measurement Location	Hydrophone Depth	Distance to Pile
Temporary Work Trestle				
Pile 2	Near-Field	26	14	36
	Far-Field	48	38	143
Pile 3	Near-Field	38	20	36
	Far-Field	48	38	168
North Trestle				
N12.5-NJ	Near-Field	38	24	33
	Far-Field	32	28	100
N11-NG	Near-Field	36	18	33
	Far-Field	38	30	140
N11.5-NG	Near-Field	36	18	35
	Far-Field	38	30	140
Passenger Only Ferry Floats				
POF-E	Near-Field	34	20	45
	Far-Field	30	24	175
POF-D	Near-Field	34	18	58
	Far-Field	36	26	160
POF-F	Near-Field	34	18	33
	Far-Field	36	26	181
South Notch				
S26-SG	Near-Field	37	24	31
	Far-Field	37	24	115
S26-SF.3	Near-Field	37	24	32
	Far-Field	37	24	80
S26-SE.5	Near-Field	37	24	36
	Far-Field	37	24	65

7.0 IMPACT PILE DRIVING ANALYSIS AND RESULTS

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. The marine mammal functional hearing groups are provided in Table 7.1. 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.

Table 7.1 Marine Mammal Functional Hearing Groups

Functional Hearing Group	Low Frequency	High Frequency
Low-Frequency Cetaceans	7 Hz	20 kHz
Mid-Frequency Cetaceans	150 Hz	20 kHz
High-Frequency Cetaceans	200 Hz	20 kHz
Pinnipeds	75 Hz	20 kHz

Source: NOAA Guidance Document: "Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals" dated January 31, 2012

Standard deviation and L_{50} were calculated using decibel values and mean values were calculated using mean sound pressure levels.

Data analysis was conducted for each marine mammal functional hearing group by applying a band pass filter to remove frequencies from the signal that are not included in the functional hearing group being analyzed. These filters provide a roll-off of more than 40 dB per decade. In addition to the marine mammal functional hearing groups, the data was also analyzed without the band pass filter to produce broadband results.

The RMS_{90} was established between the 5^{th} percentile and 95^{th} 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.

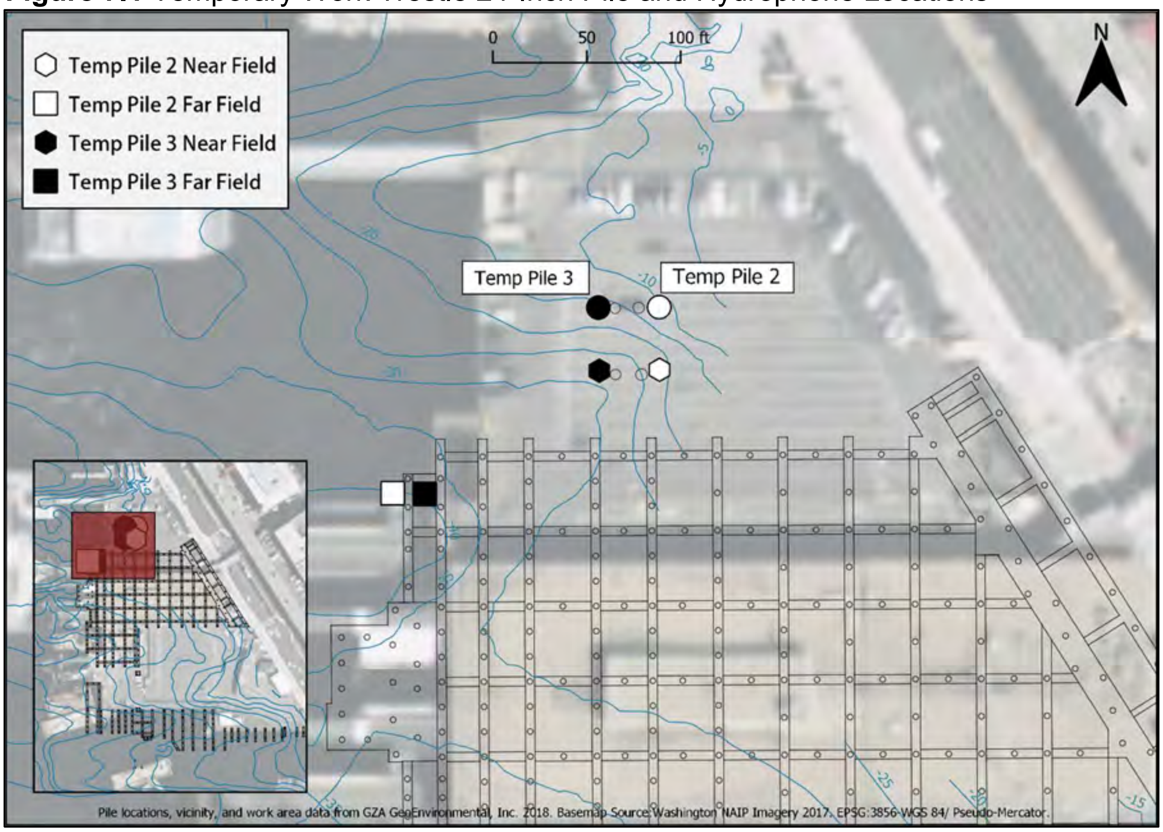
Details and results of the hydroacoustic monitoring at the temporary work platform, North Trestle, Passenger Only Ferry Floats, and South Notch are provided in Section 7.1 through Section 7.4.

7.1 Temporary Work Trestle 24-Inch Piles

Hydroacoustic data was collected during the installation of two 24-inch steel pipe piles at the Temporary Work Trestle during the afternoon of October 21, 2017. During the measurements the water temperature was approximately 55 degrees Fahrenheit and there was no precipitation. During the drive of Pile 2 the ICE I-100 V2 diesel impact hammer was misfiring and the piston height varied throughout the pile drive.

Both the near and far-field hydrophones were suspended from portions of the existing Colman Dock and a direct path of acoustical transmission was maintained between the near-field hydrophone and the piles during all pile driving. The sound paths between the far-field hydrophone and piles were likely obstructed by piles supporting the existing dock. The locations of the hydrophones and the piles are shown in Figure 7.1.

Figure 7.1 Temporary Work Trestle 24-Inch Pile and Hydrophone Locations



A summary of underwater sound levels produced by impact pile driving for the Temporary Work Trestle are shown in Table 7.2 and Table 7.3.

Table 7.2 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	166	181	2.9	178	178	154	163	2.2	162	162	144	153	2.1	152	152	174
7 Hz - 20 kHz	166	181	2.9	178	178	154	163	2.2	162	162	144	153	2.2	152	152	174
150 Hz - 20 kHz	166	181	2.9	178	178	151	167	3.1	165	165	138	151	3.1	149	149	171
200 Hz - 20 kHz	166	181	2.9	178	178	151	167	3.0	165	165	138	151	3.2	149	149	171
75 Hz - 20 kHz	166	181	2.9	178	178	152	167	3.4	165	165	139	151	2.9	149	150	172
Far-Field Hydrophone (143 feet from pile)																
Unweighted	151	161	1.7	160	160	143	152	1.8	151	152	135	143	1.8	142	143	165
7 Hz - 20 kHz	151	161	1.7	160	160	143	152	1.9	151	151	135	143	1.8	142	143	165
150 Hz - 20 kHz	151	161	1.7	160	160	131	144	2.9	142	142	122	133	2.6	131	132	154
200 Hz - 20 kHz	151	161	1.7	160	160	130	143	2.9	141	141	121	132	2.6	130	131	153
75 Hz - 20 kHz	151	161	1.7	160	160	133	145	2.7	143	143	125	135	2.4	133	134	156

Table 7.3 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 36 feet from pile, reported levels normalized to 33 feet)																
Unweighted	166	194	3.5	190	190	155	176	3.0	174	174	147	166	2.8	164	164	185
7 Hz - 20 kHz	166	194	3.5	190	190	155	178	3.2	174	174	146	166	2.8	164	164	185
150 Hz - 20 kHz	166	194	3.5	190	190	147	181	4.5	179	179	139	166	3.6	163	164	184
200 Hz - 20 kHz	166	194	3.5	190	190	146	181	4.5	179	179	138	166	3.6	163	164	184
75 Hz - 20 kHz	166	194	3.5	190	190	148	181	4.4	179	179	140	166	3.4	163	164	184
Far-Field Hydrophone (168 feet from pile)																
Unweighted	151	175	2.7	172	172	139	158	2.0	156	157	131	149	2.1	148	148	169
7 Hz - 20 kHz	151	175	2.7	172	172	139	158	2.0	156	157	131	149	2.1	148	148	169
150 Hz - 20 kHz	151	175	2.7	172	172	132	163	3.9	160	160	124	148	3.2	146	146	167
200 Hz - 20 kHz	151	175	2.7	172	172	131	163	3.9	160	160	123	148	3.2	146	146	167
75 Hz - 20 kHz	151	175	2.7	172	172	135	162	3.6	160	160	127	148	2.9	146	147	167

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 North Trestle 36-Inch Piles

Hydroacoustic data was collected during impact pile driving of three 36-inch steel pipe piles. N12.5-NJ was driven the afternoon of December 7, 2018 and N11-NG and N11.5-NG were driven the afternoon of January 10, 2019. On December 7 the water temperature was approximately 52 degrees Fahrenheit and the water temperature was 50 degrees on January 10. There was no precipitation during either day of measurements.

Both hydrophones were suspended from portions of the existing Colman Dock structure. The near-field hydrophone maintained an unobstructed sound path to the piles. An unobstructed acoustic transmission path was unable to be established for the far-field hydrophone on December 7.

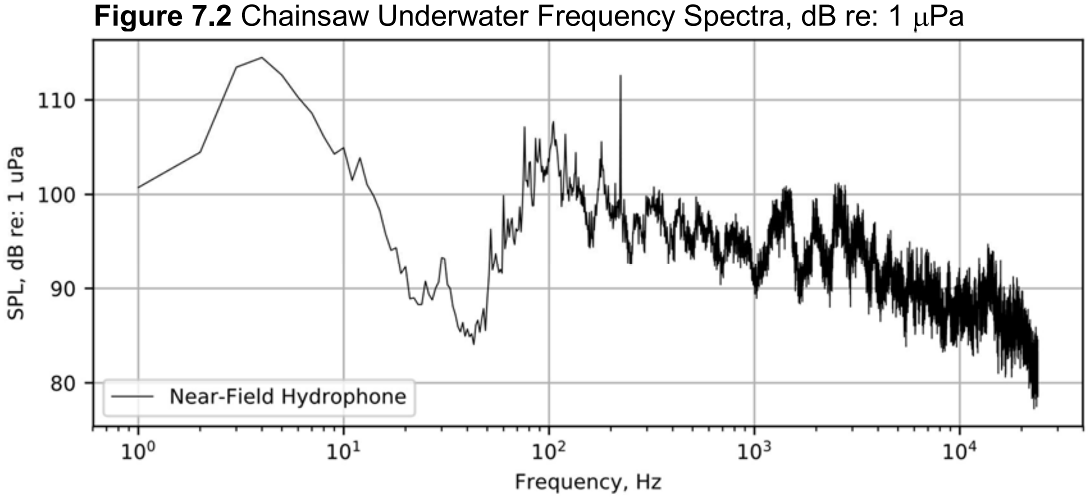
Soft start procedures were used prior to driving N12.5-NJ. Vibratory pile driving was occurring in other work areas during the measurements of N12.5-NJ and N11.5-NG. During the installation of N12.5-NJ the Passenger Only Ferry Float piles were being driven with a vibratory hammer. Piles were also being driven west of the North Trestle work area with a vibratory hammer during the beginning of impact pile driving of N11.5-NG.

In addition to vibratory pile driving, a diver was using an underwater chainsaw prior to impact pile driving on January 10, 2019. Although not required, hydroacoustic measurements were made of the chainsaw and analyzed to determine the resulting underwater sound levels. The resulting 1-second RMS, SEL and peak sound levels were calculated and are shown in Table 7.4 below. The underwater frequency spectrum from the chainsaw is shown in Figure 7.2.

Table 7.4 Chainsaw Underwater Sound Levels, dB re: 1 μPa

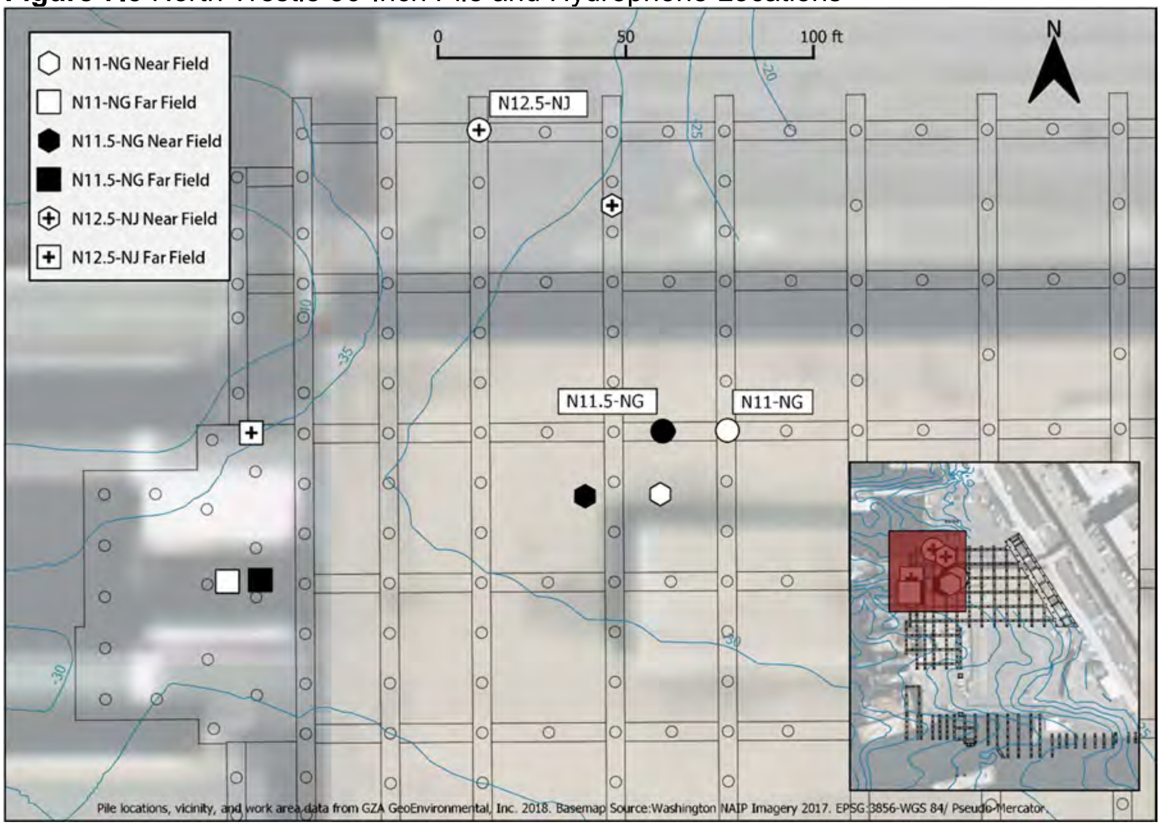
Frequency Range	Peak					1-Second RMS					SEL					cSEL
	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	Min	Max	SD	Mean	L_{50}	
Unweighted	148	159	2.7	154	152	131	140	2.8	137	137	131	140	2.8	137	137	152
7 Hz - 20 kHz	148	159	2.7	154	152	130	140	2.8	137	137	130	140	2.8	137	137	152
150 Hz - 20 kHz	148	159	2.7	154	152	129	140	3.2	137	137	129	140	3.2	137	137	151
200 Hz - 20 kHz	148	159	2.7	154	152	129	140	3.3	137	137	129	140	3.3	137	137	151
75 Hz - 20 kHz	148	159	2.7	154	152	130	140	2.9	137	137	130	140	2.9	137	137	151

Figure 7.2 Chainsaw Underwater Frequency Spectra, dB re: 1 μPa



The locations of the hydrophones and the piles are shown in Figure 7.3.

Figure 7.3 North Trestle 36-Inch Pile and Hydrophone Locations



A summary of underwater sound levels produced by impact pile driving for the North Trestle are shown in Table 7.5 to Table 7.7.

Table 7.5 N12.5-NJ 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 (33 feet from pile)																
Unweighted	178	193	2.8	187	187	167	176	1.8	172	172	158	166	1.6	162	162	187
7 Hz - 20 kHz	178	193	2.8	187	187	166	176	2.2	172	172	158	166	1.7	162	162	186
150 Hz - 20 kHz	178	193	2.8	187	187	163	177	3.9	173	173	152	163	3.0	159	159	184
200 Hz - 20 kHz	178	193	2.8	187	187	162	177	4.0	173	173	151	163	3.1	159	159	183
75 Hz - 20 kHz	178	193	2.8	187	187	164	178	3.3	173	173	153	164	2.6	160	160	185
Far-Field Hydrophone (100 feet from pile)																
Unweighted	161	177	4.0	171	170	150	163	3.0	157	157	142	152	2.2	147	147	171
7 Hz - 20 kHz	161	177	4.0	171	170	150	164	3.1	157	157	141	152	2.4	147	147	171
150 Hz - 20 kHz	161	177	4.0	171	170	144	162	5.3	157	157	135	149	4.1	145	144	169
200 Hz - 20 kHz	161	177	4.0	171	170	143	162	5.7	157	156	134	149	4.5	144	144	169
75 Hz - 20 kHz	161	177	4.0	171	170	146	163	4.4	158	157	137	151	3.4	145	145	170

Table 7.6 N11-NG 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 (33 feet from pile)																
Unweighted	182	198	2.7	194	195	157	186	4.6	182	182	140	172	3.6	168	169	194
7 Hz - 20 kHz	182	198	2.7	194	195	157	186	4.6	182	182	140	172	3.6	168	169	194
150 Hz - 20 kHz	182	198	2.7	194	195	158	187	4.7	182	183	140	172	4.2	168	169	194
200 Hz - 20 kHz	182	198	2.7	194	195	158	186	4.7	182	183	140	171	4.2	167	169	193
75 Hz - 20 kHz	182	198	2.7	194	195	158	187	4.6	182	183	140	172	3.9	168	169	194
Far-Field Hydrophone (140 feet from pile)																
Unweighted	160	180	2.5	176	175	138	164	1.6	162	162	130	156	1.7	154	154	180
7 Hz - 20 kHz	160	180	2.5	176	175	138	164	1.6	162	162	130	155	1.7	153	153	180
150 Hz - 20 kHz	160	180	2.5	176	175	138	167	4.4	163	163	129	154	3.6	150	151	177
200 Hz - 20 kHz	160	180	2.5	176	175	138	167	4.9	162	162	129	154	4.0	150	151	176
75 Hz - 20 kHz	160	180	2.5	176	175	138	168	3.6	163	163	130	155	2.8	151	152	177

Table 7.7 N11.5-NG 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 35 feet from pile, reported levels normalized to 33 feet)																
Unweighted	185	190	1.1	188	188	171	175	0.9	173	173	161	164	0.9	162	162	184
7 Hz - 20 kHz	185	190	1.1	188	188	171	175	0.9	173	173	161	164	0.9	162	162	184
150 Hz - 20 kHz	185	190	1.1	188	188	171	178	1.6	175	175	158	164	1.3	161	161	183
200 Hz - 20 kHz	185	190	1.1	188	188	171	178	1.7	175	175	158	164	1.4	161	161	182
75 Hz - 20 kHz	185	190	1.1	188	188	172	178	1.4	175	175	159	164	1.1	162	161	183
Far-Field Hydrophone (140 feet from pile)																
Unweighted	167	174	1.1	170	170	159	162	1.0	161	161	150	154	1.0	152	152	174
7 Hz - 20 kHz	167	174	1.1	170	170	158	162	1.1	160	160	149	153	1.0	152	151	173
150 Hz - 20 kHz	167	174	1.1	170	170	152	161	1.6	156	156	141	148	1.6	145	144	166
200 Hz - 20 kHz	167	174	1.1	170	170	151	160	1.7	156	155	140	148	1.8	144	144	165
75 Hz - 20 kHz	167	174	1.1	170	170	154	161	1.5	157	157	143	149	1.2	146	146	167

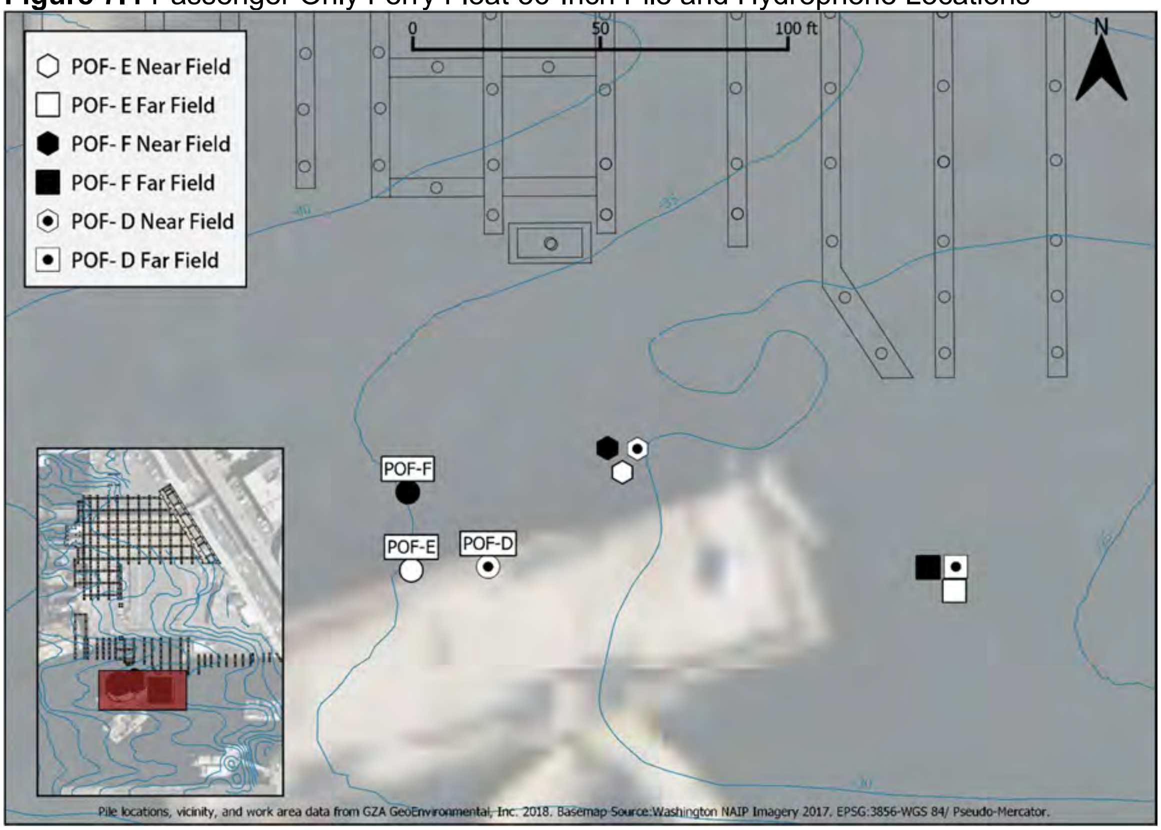
The underwater sound levels measured over the duration of each pile drive, the waveform of the of the pile strike which produced the absolute highest peak sound pressure level, and the average underwater frequency spectrum from all pile strikes are provided in the Appendix.

7.3 Passenger Only Ferry Float 36-Inch Piles

Underwater noise data was collected during impact pile driving of three 36-inch steel pipe piles for the Passenger Only Ferry (POF) Floats on December 11, 2018. During the measurements water temperature was approximately 51 degrees Fahrenheit and rain was falling at approximately 0.12 inches per hour.

The near-field hydrophone was suspended from a work skiff moored to temporary floating dock and the far-field hydrophone was deployed from a floating work platform moored to the south side of the construction site. Because of the pile locations, the near-field hydrophone was unable to be deployed 33 feet from all the piles, however an unobstructed sound path was maintained between both hydrophones and the piles during all impact pile driving. Soft start procedures were used before the drive of POF-E and POF-D. The locations of the hydrophones and the piles are provided in Figure 7.4.

Figure 7.4 Passenger Only Ferry Float 36-Inch Pile and Hydrophone Locations



A summary of underwater sound levels produced by impact pile driving for the Passenger Only Ferry Floats are shown in Table 7.8 to Table 7.10.

Table 7.8 POF-E 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 45 feet from pile, reported levels normalized to 33 feet)																
Unweighted	174	197	4.9	192	192	158	183	5.1	178	178	149	171	4.4	166	166	182
7 Hz - 20 kHz	174	197	4.9	192	192	158	183	5.0	178	178	149	171	4.4	166	166	182
150 Hz - 20 kHz	174	197	4.9	192	192	160	183	4.7	178	179	147	170	4.6	166	166	182
200 Hz - 20 kHz	174	197	4.9	192	192	160	183	4.7	178	178	147	170	4.6	165	165	182
75 Hz - 20 kHz	174	197	4.9	192	192	160	183	4.7	179	179	148	171	4.5	166	166	182
Far-Field Hydrophone (175 feet from pile)																
Unweighted	165	187	4.4	184	184	151	173	4.6	170	170	143	163	4.1	160	161	177
7 Hz - 20 kHz	165	187	4.4	184	184	151	173	4.7	170	170	143	162	4.2	160	161	177
150 Hz - 20 kHz	165	187	4.4	184	184	151	174	4.6	171	171	140	162	4.5	160	160	176
200 Hz - 20 kHz	165	187	4.4	184	184	151	174	4.5	171	171	140	162	4.5	160	160	176
75 Hz - 20 kHz	165	187	4.4	184	184	151	174	4.6	171	171	141	162	4.4	160	161	177

Table 7.9 POF-D 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 58 feet from pile, reported levels normalized to 33 feet)																
Unweighted	184	205	3.1	202	203	170	191	3.1	189	189	157	178	3.0	176	176	193
7 Hz - 20 kHz	184	205	3.1	202	203	171	191	3.0	189	189	157	178	3.0	176	176	193
150 Hz - 20 kHz	184	205	3.1	202	203	171	191	2.9	189	189	156	177	3.0	175	175	193
200 Hz - 20 kHz	184	205	3.1	202	203	171	191	2.9	189	189	156	177	3.1	175	175	193
75 Hz - 20 kHz	184	205	3.1	202	203	171	191	2.9	189	189	157	178	3.0	176	176	193
Far-Field Hydrophone (160 feet from pile)																
Unweighted	172	194	3.1	191	191	157	182	3.7	179	178	147	169	3.1	166	166	184
7 Hz - 20 kHz	172	194	3.1	191	191	157	182	3.7	179	179	147	169	3.1	166	166	184
150 Hz - 20 kHz	172	194	3.1	191	191	160	181	3.2	179	178	146	168	3.2	166	165	183
200 Hz - 20 kHz	172	194	3.1	191	191	159	181	3.2	178	178	145	168	3.3	165	165	183
75 Hz - 20 kHz	172	194	3.1	191	191	159	182	3.3	179	179	147	169	3.2	166	166	184

Table 7.10 POF-F 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 (33 feet from pile)																
Unweighted	194	203	1.2	201	200	179	187	1.4	185	185	165	173	1.2	171	172	190
7 Hz - 20 kHz	194	203	1.2	201	200	179	188	1.4	185	185	165	173	1.2	171	172	190
150 Hz - 20 kHz	194	203	1.2	201	200	179	188	1.4	186	186	164	173	1.3	171	171	190
200 Hz - 20 kHz	194	203	1.2	201	200	178	188	1.4	186	186	164	173	1.3	171	171	190
75 Hz - 20 kHz	194	203	1.2	201	200	179	188	1.4	186	186	165	173	1.3	171	171	190
Far-Field Hydrophone (181 feet from pile)																
Unweighted	180	193	1.5	189	188	165	176	1.4	173	173	156	167	1.2	164	164	183
7 Hz - 20 kHz	180	193	1.5	189	188	165	176	1.4	173	173	156	167	1.2	164	164	183
150 Hz - 20 kHz	180	193	1.5	189	188	167	180	1.6	177	177	155	166	1.3	163	164	182
200 Hz - 20 kHz	180	193	1.5	189	188	167	180	1.6	177	177	154	166	1.4	163	163	182
75 Hz - 20 kHz	180	193	1.5	189	188	168	180	1.5	177	177	156	166	1.3	164	164	182

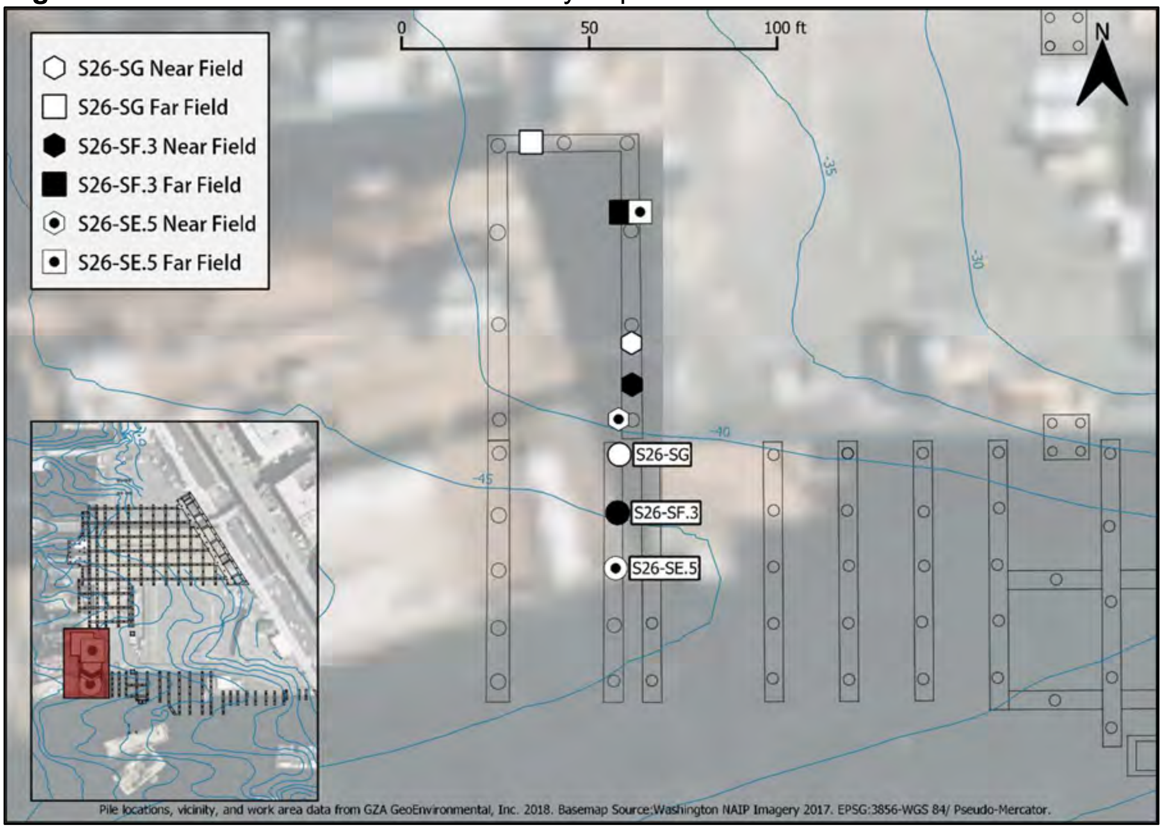
Underwater sound levels measured over the duration of each pile drive, waveform of the pile strike which produced the absolute highest peak sound pressure level, and average underwater frequency spectrum from all pile strikes are provided in the Appendix.

7.4 South Notch Piles 36-Inch Piles

Hydroacoustic data was collected the morning of December 14, 2018 during impact pile driving of three 36-inch steel pipe piles at the South Notch. Water temperature during the measurements was 51 degrees Fahrenheit and there was no precipitation.

Both hydrophones were suspended from existing portions of Colman Dock and maintained a direct line of acoustic transmission to the monitored piles. S26-SG was the first pile driven and included the required soft start procedure. After the soft start the pile was driven, the hammer stopped, and then the pile was driven one additional foot. Early in the drive of S26-SE.5 there was a problem with impact hammer that required setting the hammer down for repairs. Upon completing the repairs the pile drive was completed. The locations of the hydrophones and piles are provided in Figure 7.5.

Figure 7.5 South Notch 36-Inch Pile and Hydrophone Locations



A summary of underwater sound levels produced by impact pile driving at the South Notch are shown in Table 7.11 to Table 7.13.

Table 7.11 S26-SG 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 31 feet from pile, reported levels normalized to 33 feet)																
Unweighted	185	207	2.3	204	204	171	195	2.3	193	193	160	182	2.1	179	180	202
7 Hz - 20 kHz	185	207	2.3	204	204	172	195	2.2	193	193	160	182	2.1	179	180	202
150 Hz - 20 kHz	185	207	2.3	204	204	173	195	2.2	193	193	159	181	2.2	179	179	202
200 Hz - 20 kHz	185	207	2.3	204	204	173	195	2.2	192	193	159	181	2.2	179	179	201
75 Hz - 20 kHz	185	207	2.3	204	204	173	195	2.1	193	193	160	182	2.2	179	180	202
Far-Field Hydrophone (65 feet from pile)																
Unweighted	178	194	1.3	194	194	164	187	2.2	185	185	151	174	2.3	172	172	194
7 Hz - 20 kHz	178	194	1.3	194	194	164	187	2.2	185	185	151	174	2.3	172	172	194
150 Hz - 20 kHz	178	194	1.3	194	194	164	187	2.2	185	185	150	174	2.3	172	172	194
200 Hz - 20 kHz	178	194	1.3	194	194	164	187	2.2	185	185	150	173	2.3	172	171	194
75 Hz - 20 kHz	178	194	1.3	194	194	164	187	2.2	185	185	151	174	2.3	172	172	194

Table 7.12 S26-SF.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 (32 feet from pile)																
Unweighted	192	202	1.2	199	199	178	189	1.0	188	188	165	176	1.0	175	175	196
7 Hz - 20 kHz	192	202	1.2	199	199	179	189	1.0	188	188	165	176	1.0	175	175	196
150 Hz - 20 kHz	192	202	1.2	199	199	178	189	1.0	187	187	165	176	1.0	174	174	195
200 Hz - 20 kHz	192	202	1.2	199	199	178	188	1.0	187	187	165	175	1.0	174	174	195
75 Hz - 20 kHz	192	202	1.2	199	199	179	189	1.0	187	188	165	176	1.0	174	175	196
Far-Field Hydrophone (80 feet from pile)																
Unweighted	189	194	0.5	194	194	176	185	0.9	184	184	162	172	0.9	171	171	192
7 Hz - 20 kHz	189	194	0.5	194	194	176	185	0.9	184	184	163	172	0.9	171	171	192
150 Hz - 20 kHz	189	194	0.5	194	194	175	185	0.9	183	183	162	172	0.9	171	171	192
200 Hz - 20 kHz	189	194	0.5	194	194	175	184	0.9	183	183	162	172	0.9	170	170	192
75 Hz - 20 kHz	189	194	0.5	194	194	176	185	0.9	184	184	162	172	0.9	171	171	192

Table 7.13 S26-SE.5 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	189	206	2.4	204	204	177	194	2.3	192	192	164	179	1.9	177	177	199
7 Hz - 20 kHz	189	206	2.4	204	204	177	194	2.3	192	192	164	179	1.9	177	177	199
150 Hz - 20 kHz	189	206	2.4	204	204	176	194	2.6	191	191	163	179	2.1	177	177	199
200 Hz - 20 kHz	189	206	2.4	204	204	175	193	2.7	191	191	162	179	2.2	177	177	199
75 Hz - 20 kHz	189	206	2.4	204	204	177	194	2.4	192	192	164	179	2.0	177	177	199
Far-Field Hydrophone (115 feet from pile)																
Unweighted	181	195	1.7	193	193	170	184	1.6	181	182	157	171	1.7	169	169	191
7 Hz - 20 kHz	181	195	1.7	193	193	170	184	1.6	181	182	157	171	1.7	169	169	191
150 Hz - 20 kHz	181	195	1.7	193	193	170	184	1.6	181	181	156	171	1.7	168	168	190
200 Hz - 20 kHz	181	195	1.7	193	193	169	183	1.7	181	181	155	171	1.7	168	168	190
75 Hz - 20 kHz	181	195	1.7	193	193	170	184	1.6	181	181	157	171	1.7	169	169	191

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

8.0 DISTANCE TO 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.

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

Where $\mathrm{SPL_{D1}}$ is the sound pressure measured at a distance, D_1 and $\mathrm{SPL_{D2}}$ 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:

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

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 133 feet to allow for comparison of measured sound levels. After calculating the far-field sound levels at 133 feet, the highest mean peak, RMS_{90} and SEL values were used to calculate the distances required for sound to reach the threshold distances. 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 National Marine Fisheries Service (NMFS) has defined underwater sound level thresholds for the disturbance and injury of marine mammals. These thresholds are provided in Table 8.1.

Table 8.1 Marine Mammal Thresholds, dB re: 1 μPa (RMS)

Functional Hearing Group	Frequency Range	Underwater Sound Thresholds (RMS) for Impact Pile Driving	
		Disturbance Threshold (Level B)	Injury Threshold (Level A)
Cetaceans	7 Hz-20 kHz	160	180
	150 Hz-20 kHz		
	200 Hz-20 kHz		
Pinnipeds	75 Hz-20 kHz	160	190

Source: National Marine Fisheries Service

The distances necessary for underwater sound levels to dissipate to the marine mammal disturbance and injury thresholds were estimated using the practical spreading model and the highest average RMS sound levels measured by the far-field hydrophone. The resulting distances from impact pile driving of steel pipe piles are shown in Table 8.2 below.

Table 8.2 Distances to Marine Mammal Thresholds

Functional Hearing Group	Frequency Range	RMS_{90}[1]	Marine Mammal Detection Thresholds		Distance to Threshold[2]	
			Disturbance (Level B)	Injury (Level A)	Disturbance (Level B)	Injury (Level A)
Cetaceans	7 Hz-20 kHz	181	160	180	**3,341 feet**	**155 feet**
	150 Hz-20 kHz					
	200 Hz-20 kHz					
Pinnipeds	75 Hz-20 kHz		160	190	**3,341 feet**	**33 feet**

1. The highest mean RMS_{90} sound level was measured by the far-field hydrophone during impact pile driving of Pile S26-SG.

As shown in Table 8.2, the estimated distance required for sound generated by impact pile driving to reach the 160 dB marine mammal disturbance threshold is 3,341 feet from the pile. The estimated distances to the 180 dB and 190 dB injury threshold for cetaceans and pinnipeds are 155 feet and 33 feet respectively. Figure 8.1 illustrates the areas where underwater sound levels are expected to exceed the marine mammal disturbance and injury thresholds. 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 8.3.

Table 8.3 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 8.3 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 8.4.

Table 8.4 Distances to Fish Thresholds

Effect	Metric	Measured Sound Level	Fish Mass	Threshold	Distance
Physical Injury	Peak	192[1]	N/A	206	**16 feet**
	Daily cSEL	194[2]	< 2 grams	183	**767 feet**
			≥ 2 grams	187	**415 feet**
Effective Quiet	Single Strike SEL	168[1]	N/A	150	**2,074 feet**

1. The highest mean peak and sing strike SEL sound levels were measured by the far-field hydrophone during impact pile driving of POF-D.
2. The highest daily cSEL sound level was measured by the far-field hydrophone on December 14, 2018.
3. The highest average single strike SEL was measured by the far-field hydrophone during impact pile driving of S26-SE.5.

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 REFERENCES

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Madsen, P.T., M. Johnson, P.J.O. Miller, N. Aguilar Soto, J. Lynch and P. Tyack. “Quantitative Measures of Air-Gun Pulses Recorded on Sperm Whales (Physeter macrocephalus) Using Acoustic Tags during Controlled Exposure Experiments.” October 2006.

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NOAA Fisheries National Marine Fisheries Service “Estimated Auditory Bandwidths for Marine Mammals and Fish.”

NOAA Fisheries National Marine Fisheries Service “Marine Mammal and Fish Injury and Disturbance Thresholds for Marine Construction Activity.”

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The Greenbusch Group, Inc. “Colman Dock Phase 2 Underwater Noise Monitoring Plan.” October 25, 2018.

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Washington State Department of Transportation. “Underwater Noise Monitoring Plan Template.” August 2013.

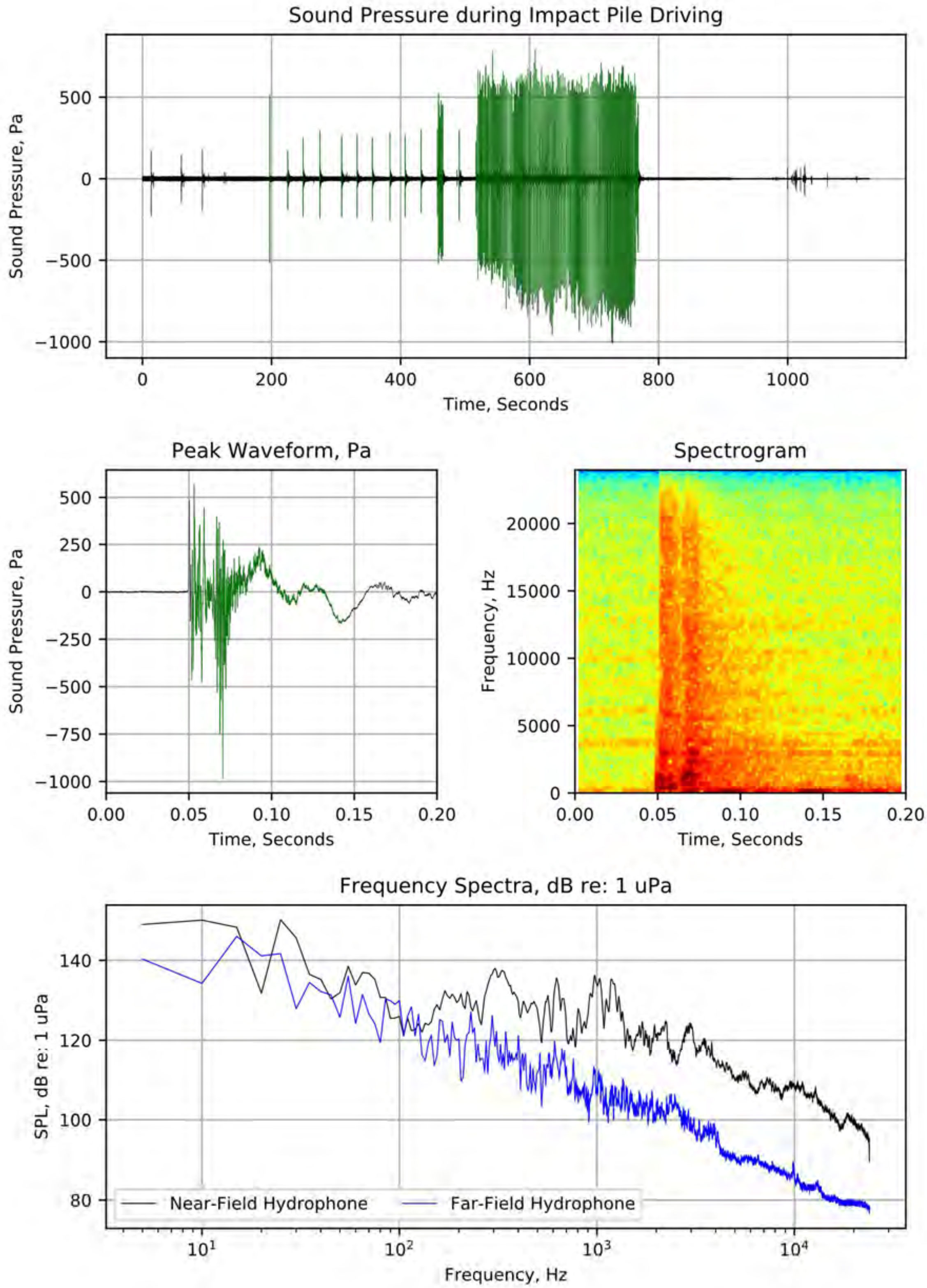
APPENDIX

Table of Contents

1.0 TEMPORARY WORK TRESTLE 24-INCH STEEL PIPE PILES

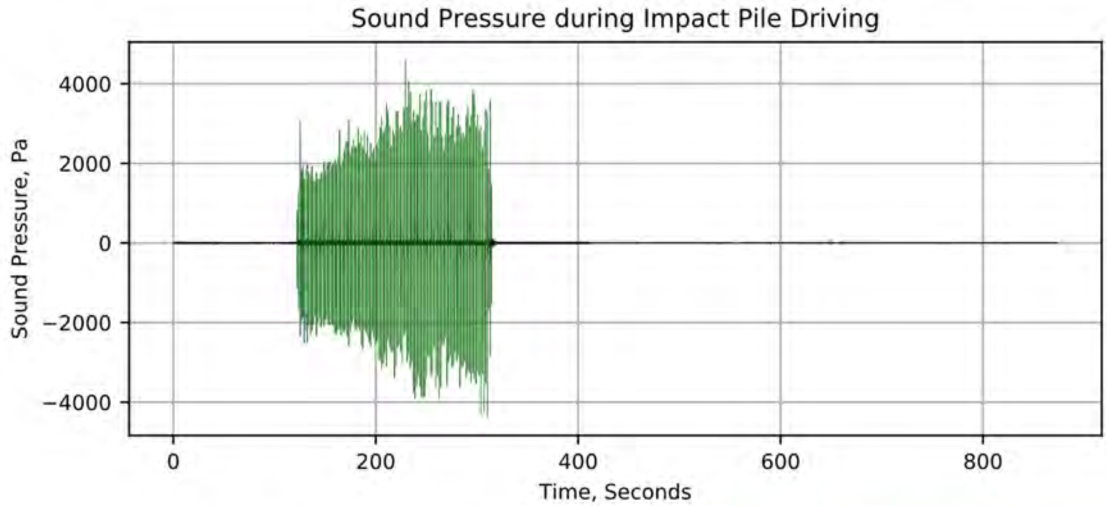
PILE – 2

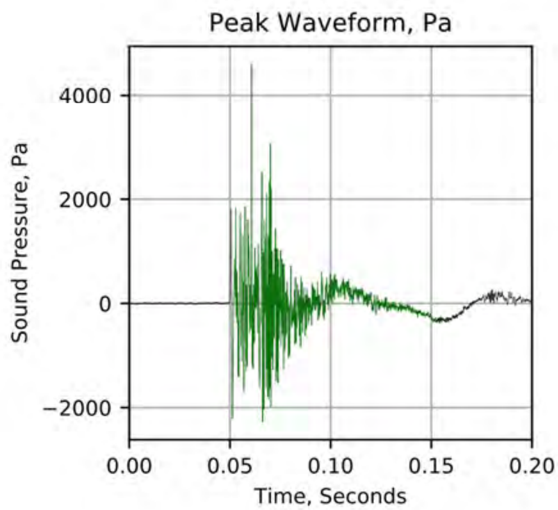
October 21, 2018

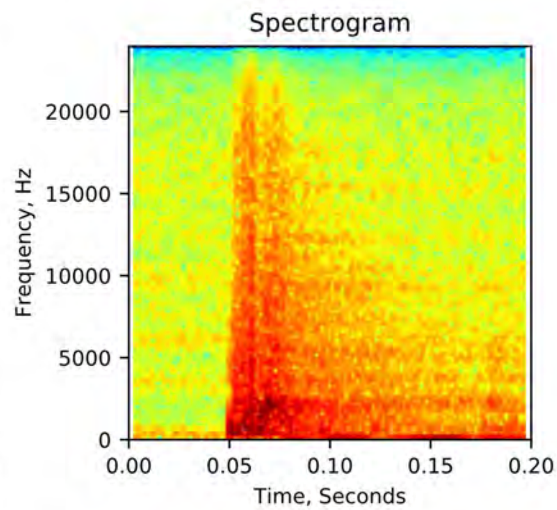


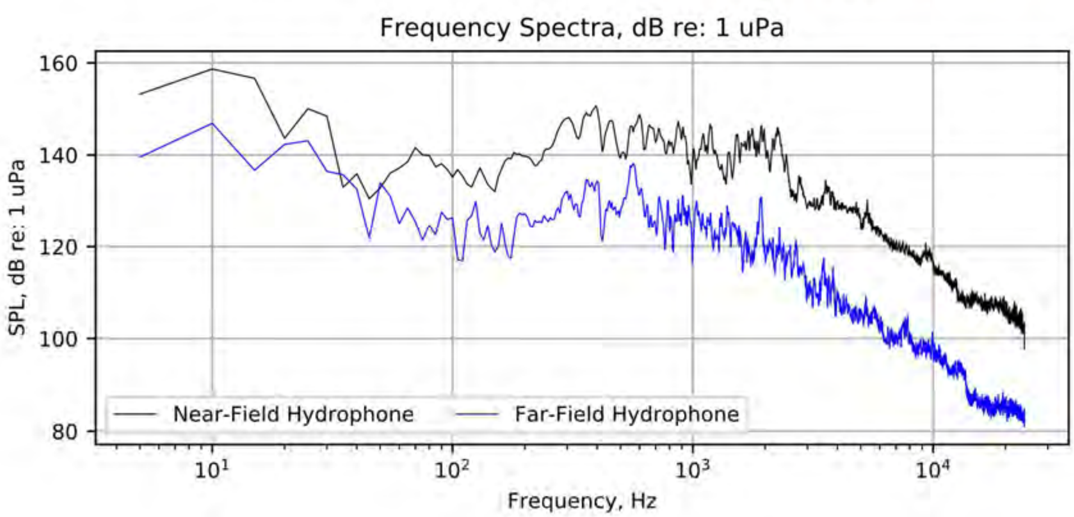
PILE – 3

October 21, 2018





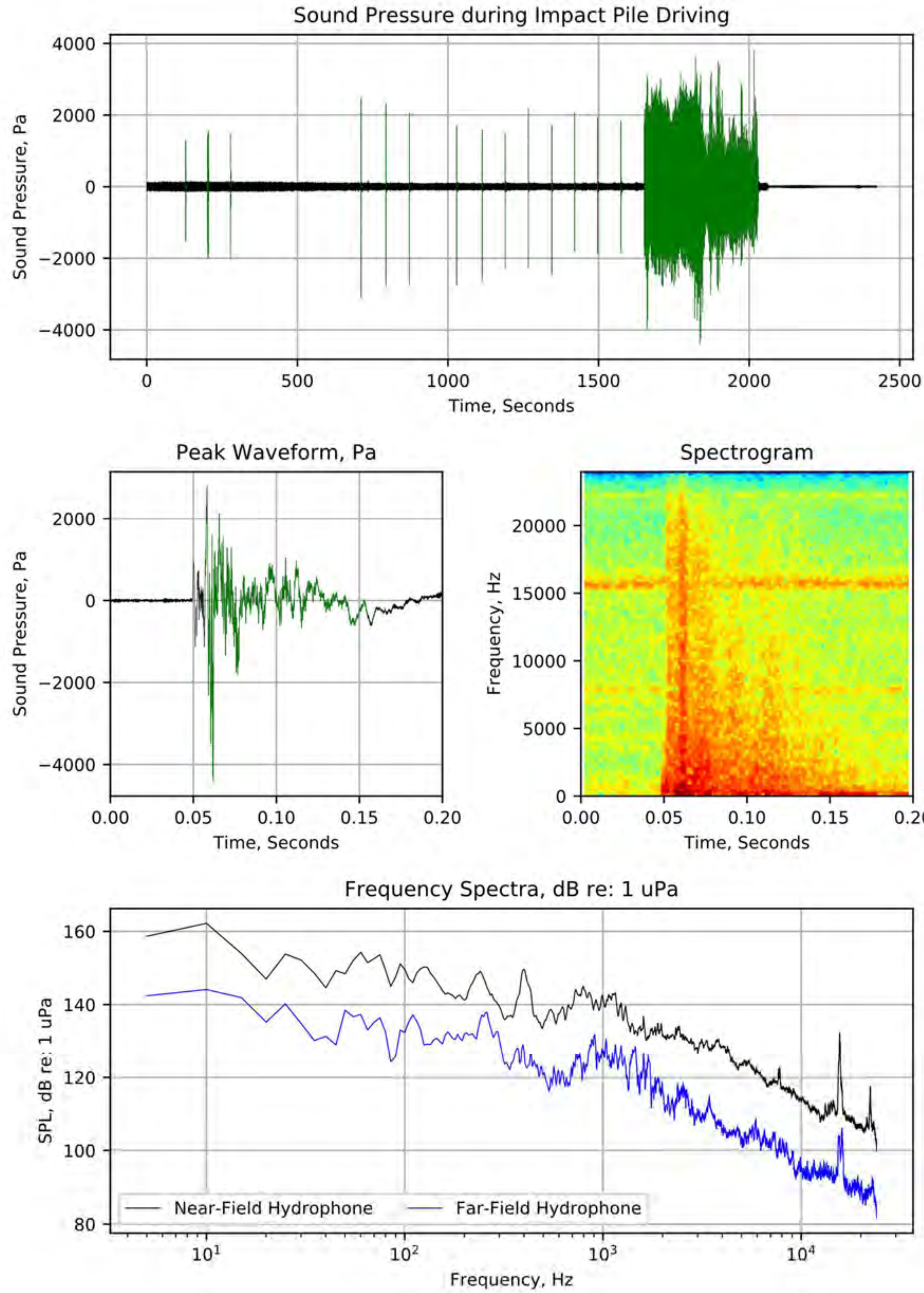




2.0 NOUTH TRESTLE 36-INCH STEEL PIPE PILES

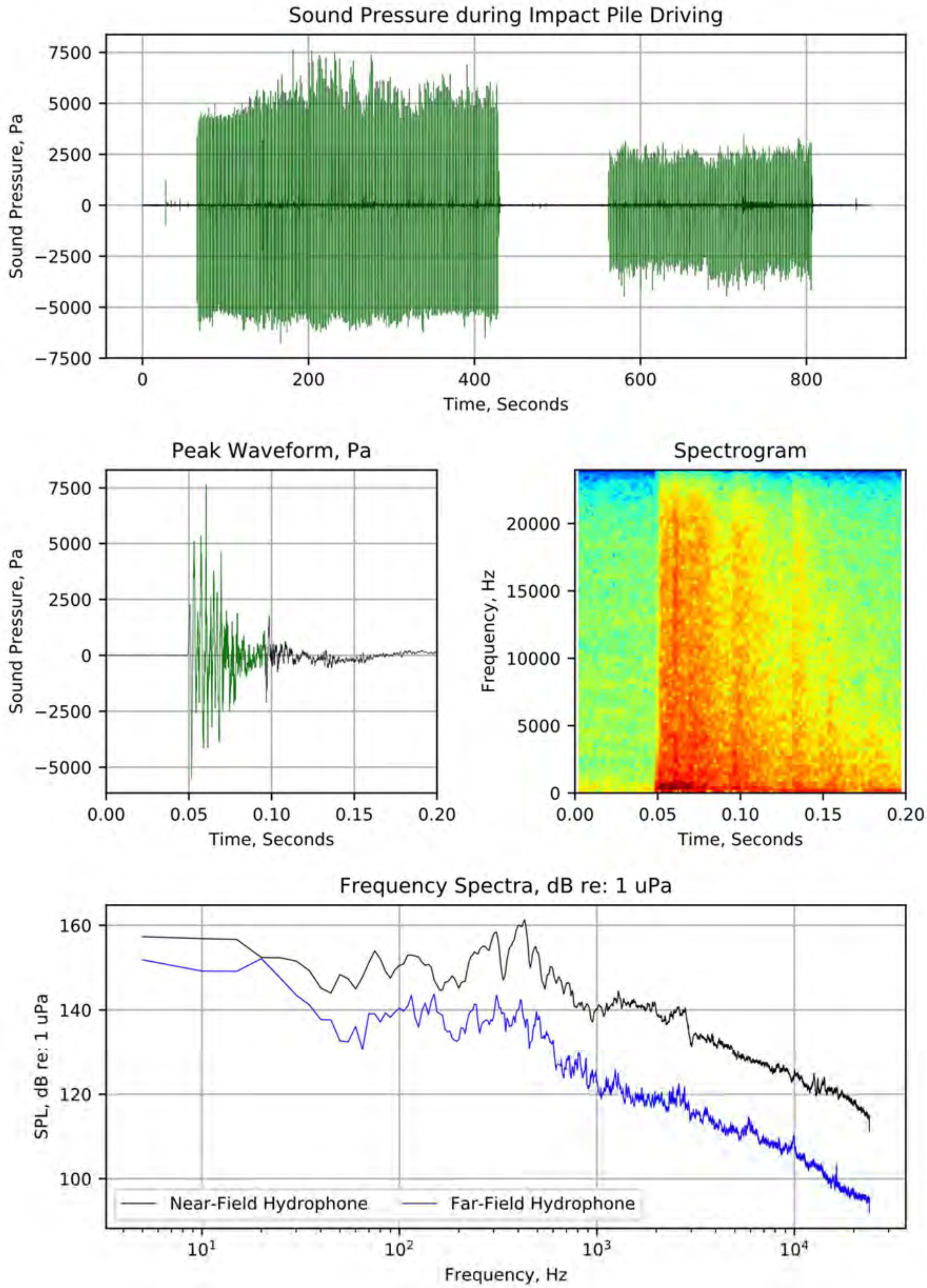
N12.5-NJ

December 7, 2018



N11-NG

January 10, 2019



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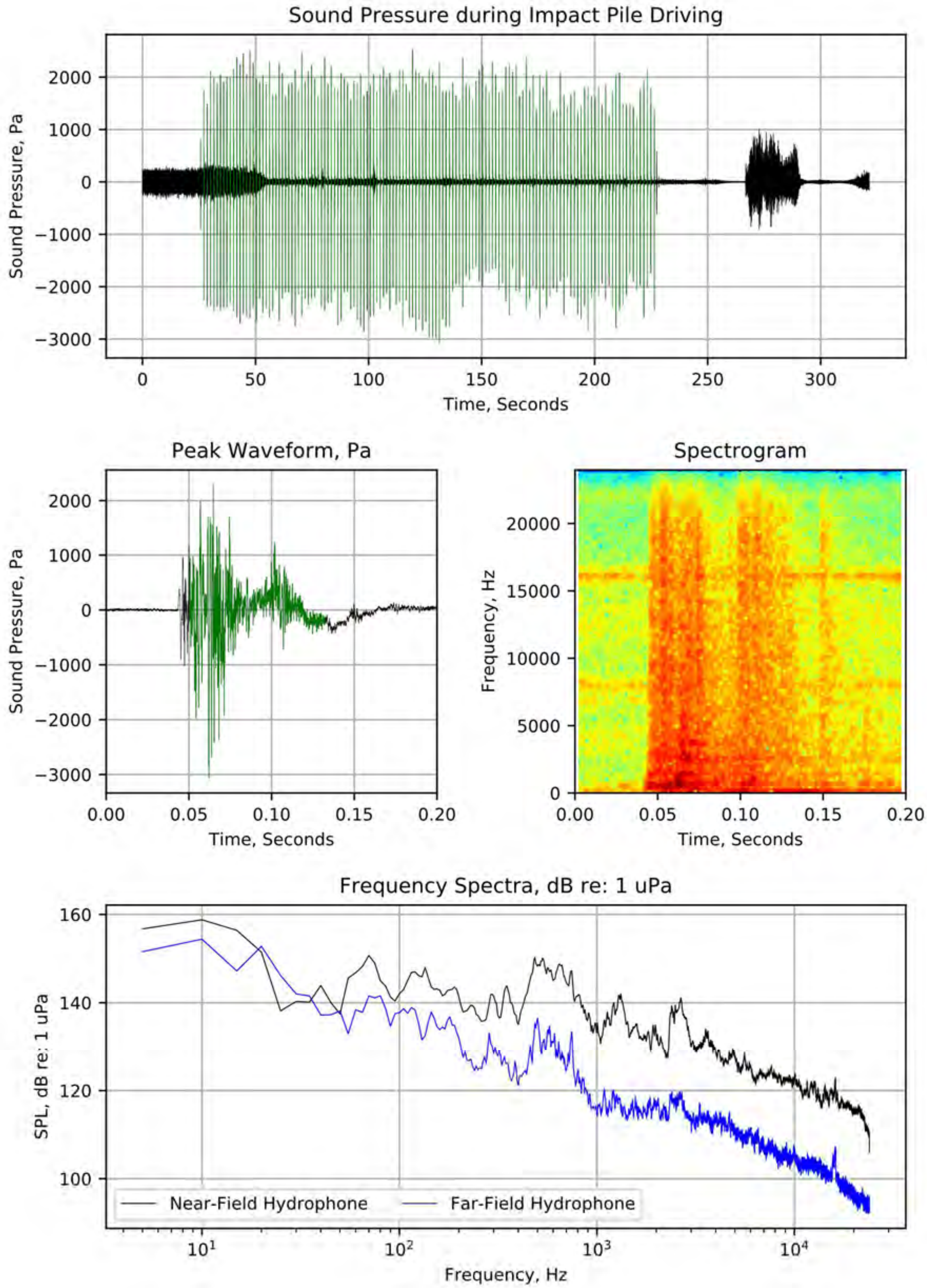
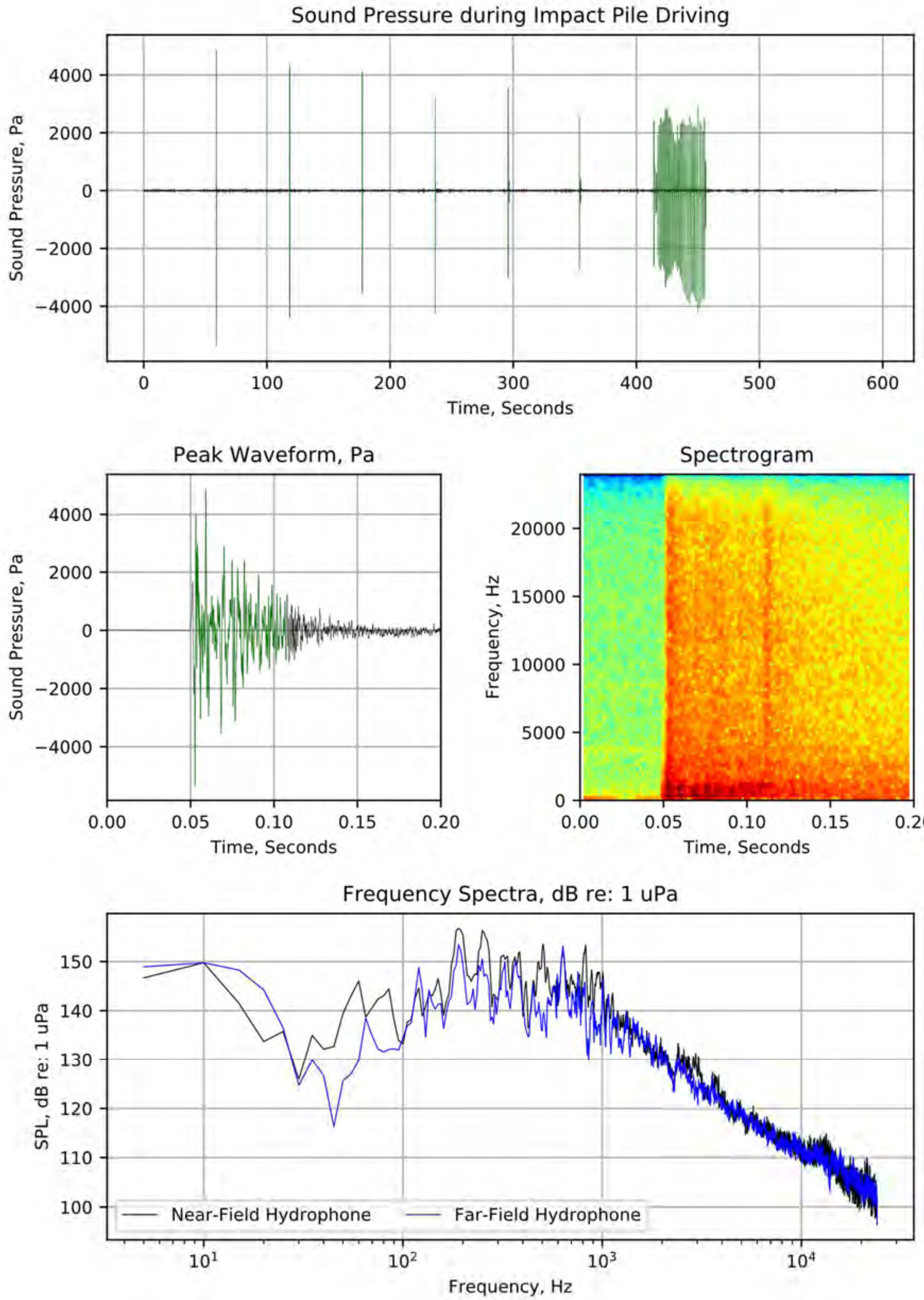


3.0 PASSENGER ONLY FERRY FLOATS 36-INCH STEEL PIPE PILES

POF-E

December 11, 2018



POF-D

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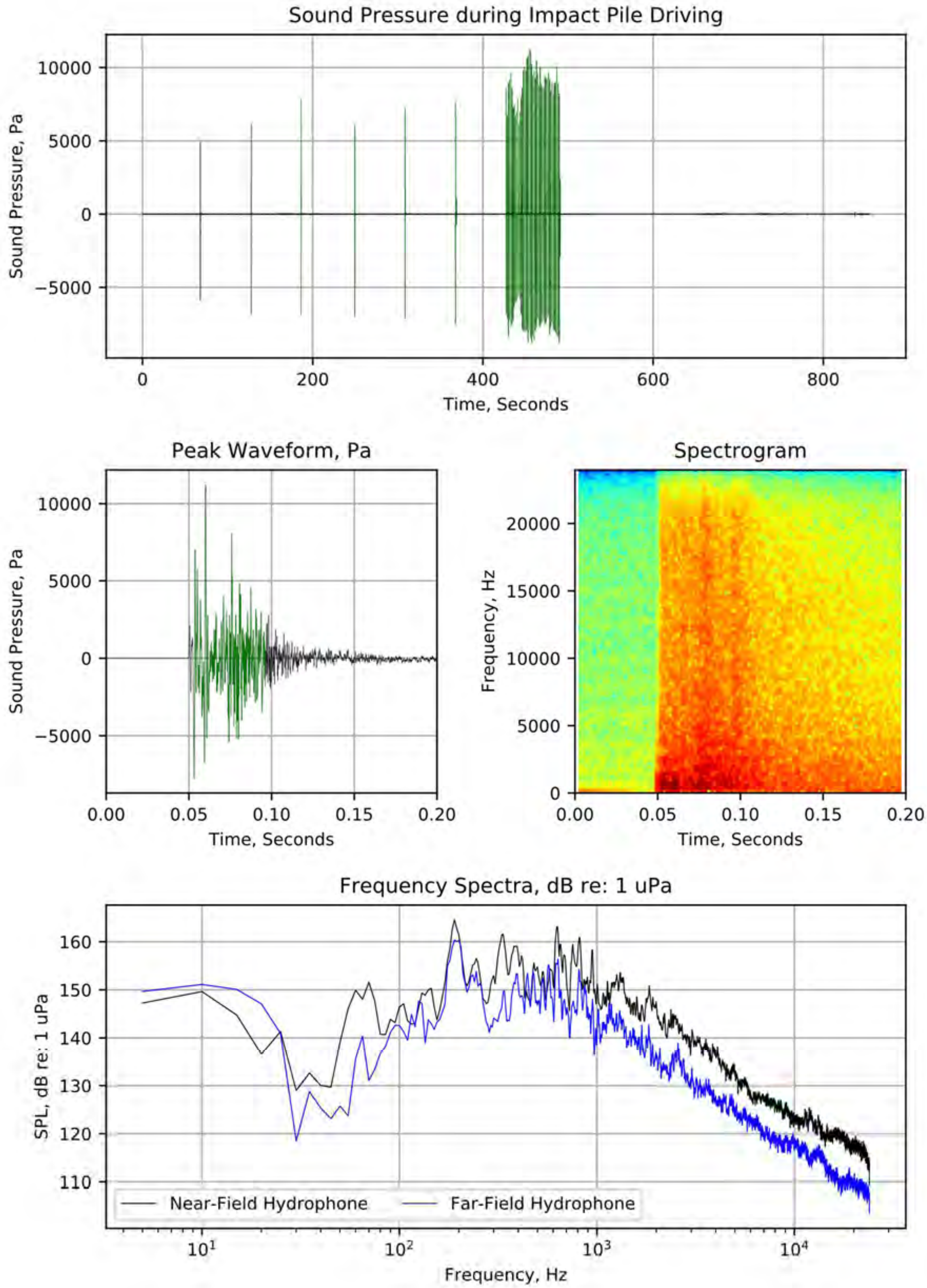

POF-F

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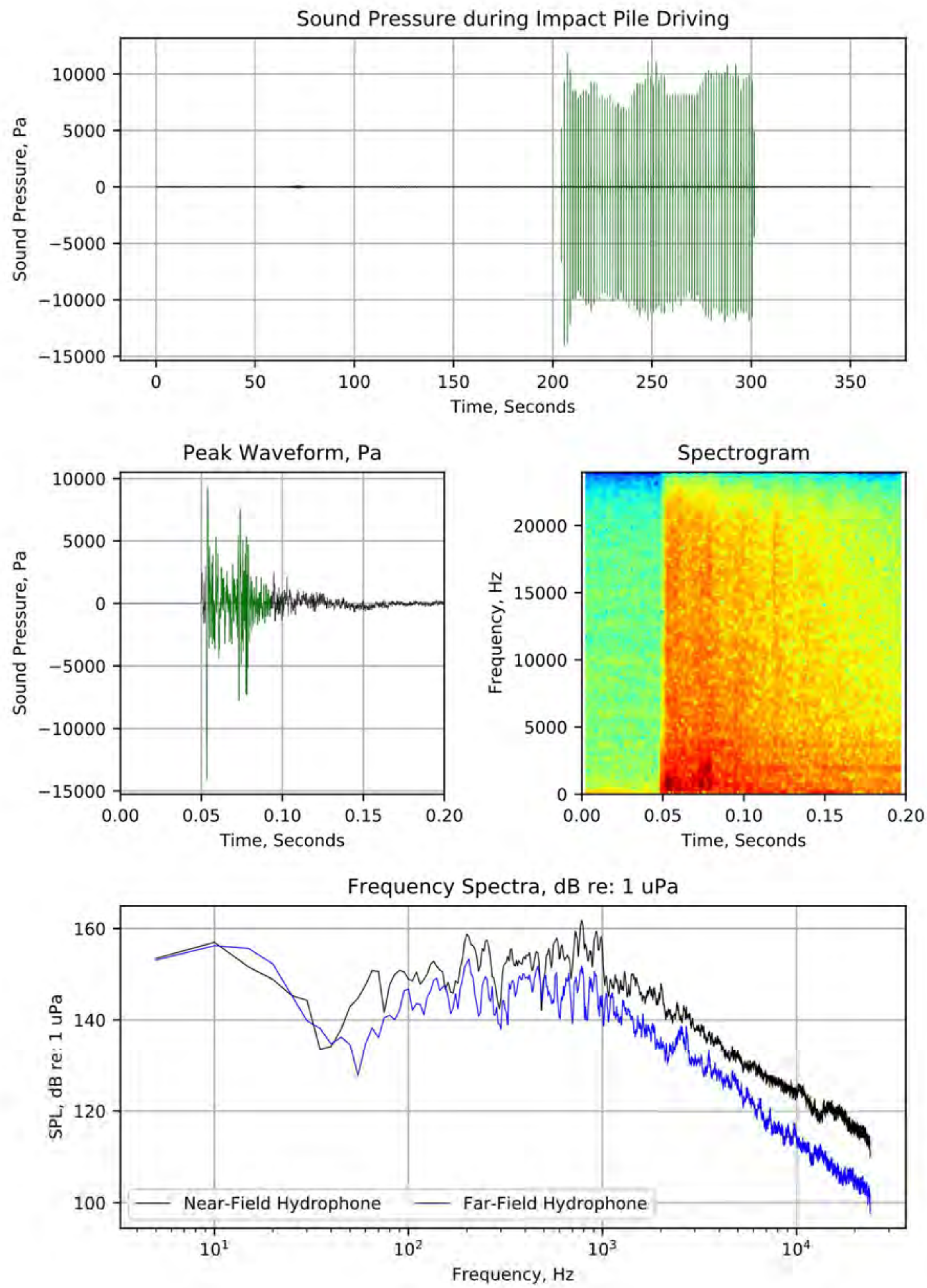
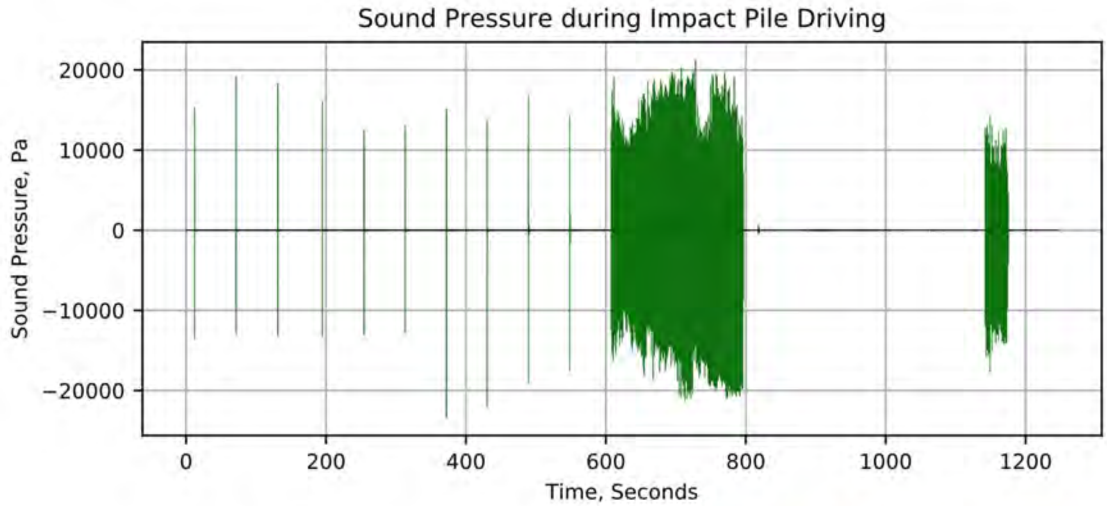
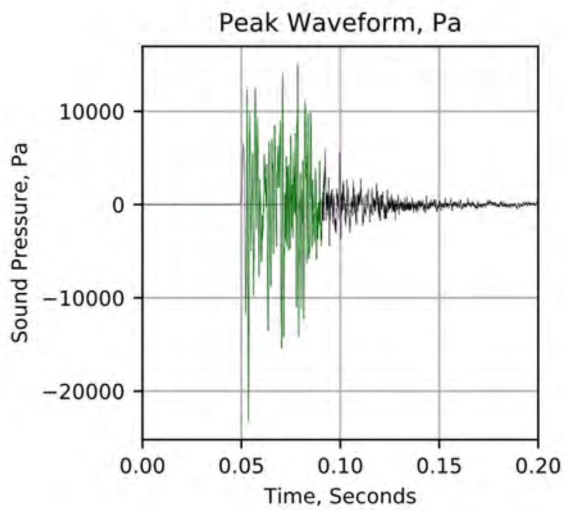


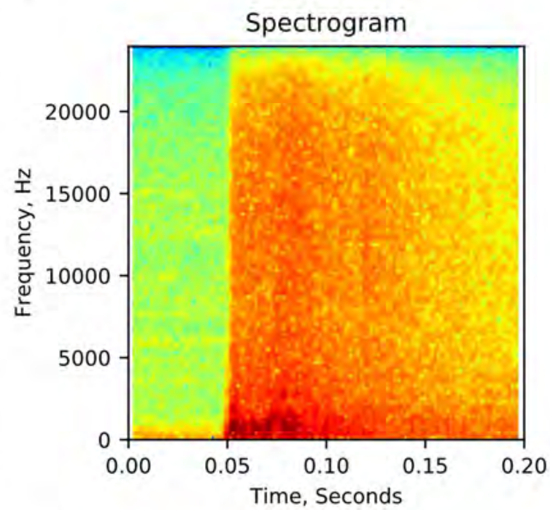
4.0 SOUTH NOTCH 36-INCH STEEL PIPE PILES

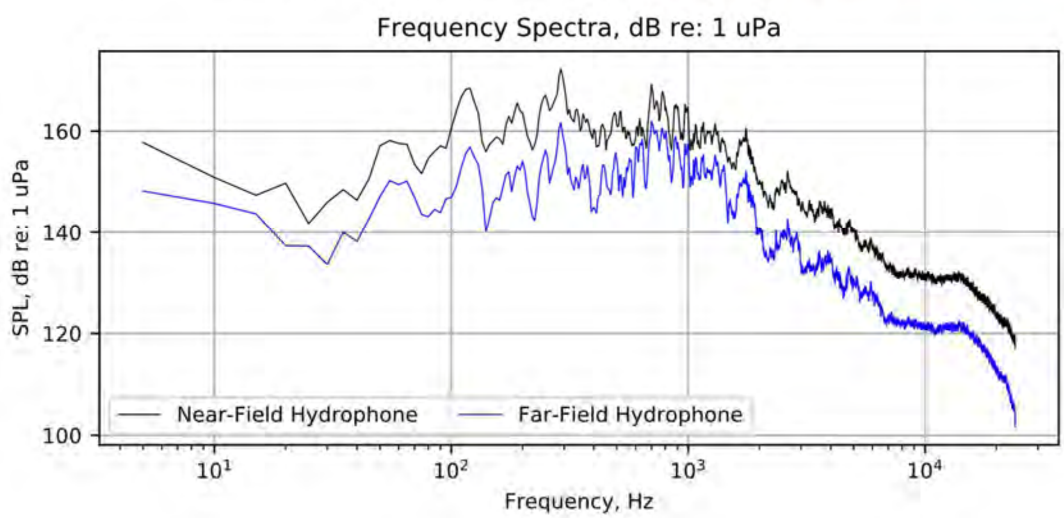
S26-SG

December 14, 2018









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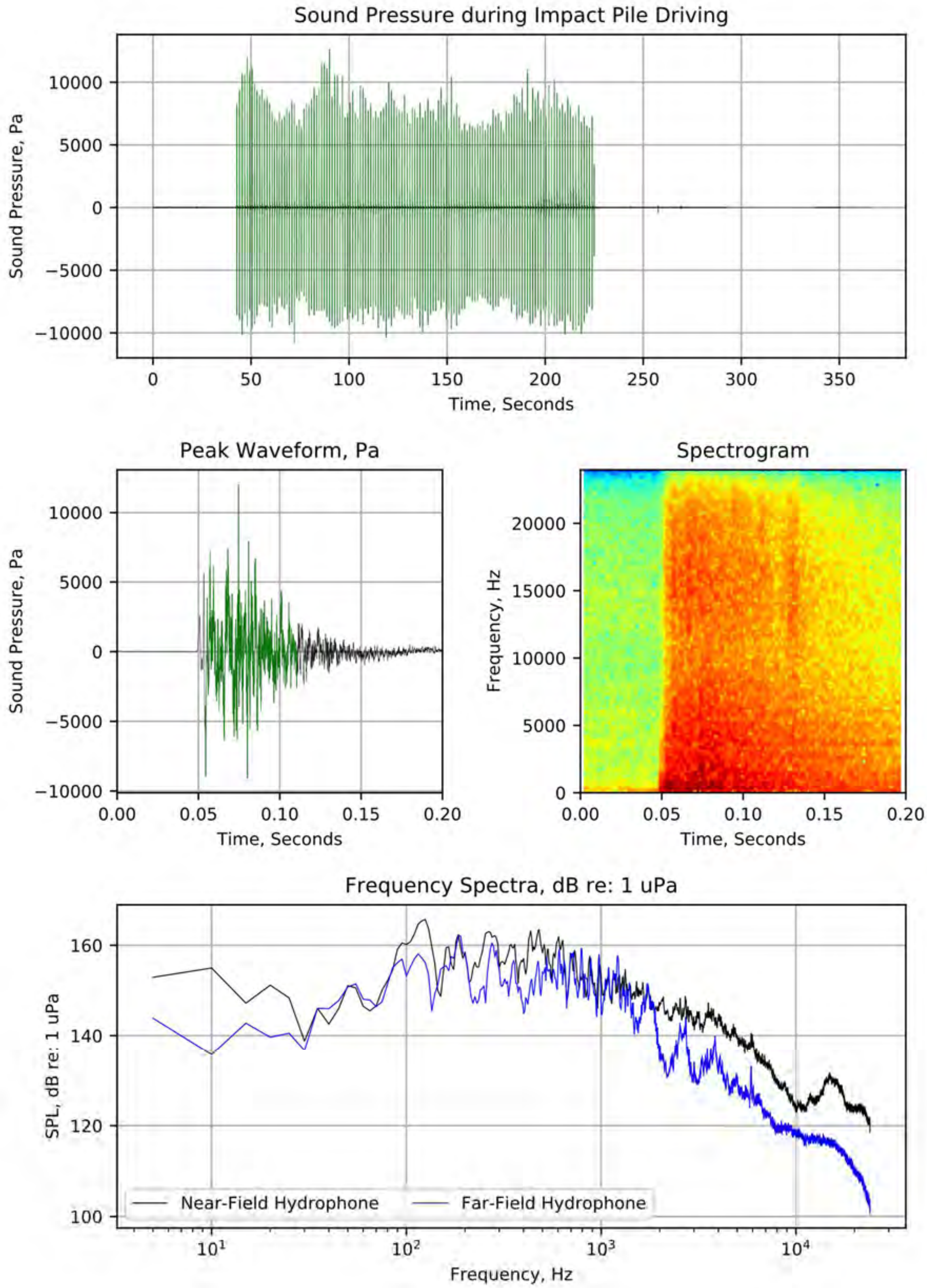
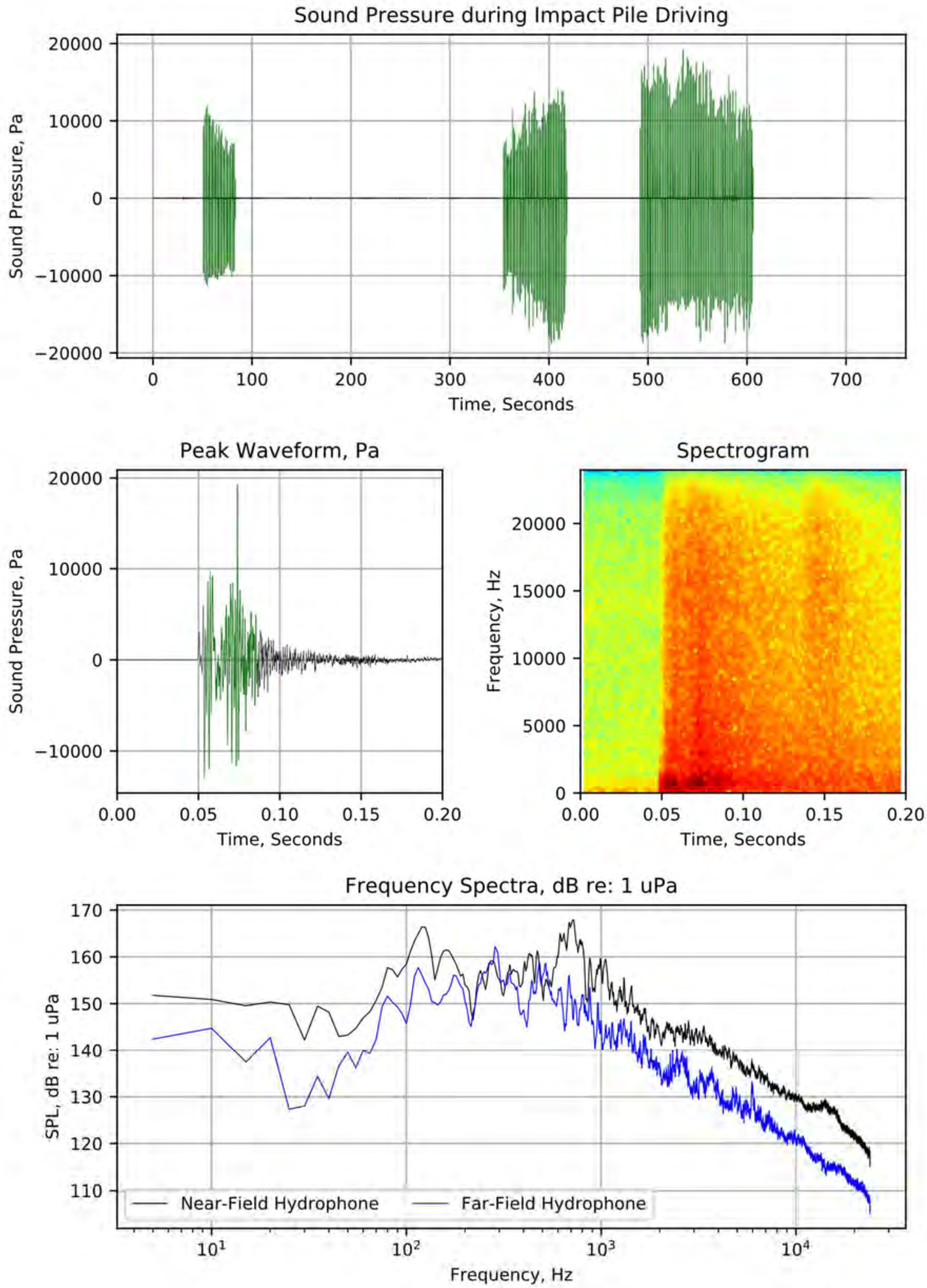
December 14, 2018



S26-SE.5

December 14, 2018



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.

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)	77,000 lbs (34,920 kg)

Optional Variable Throttle Control.

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.

Cushion material.

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

Typical 54" offshore.

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

ICE I-100V2 DIESEL IMPACT HAMMER

Ram weight
22050 lbs

Rated energy (fuel setting 4)
260385 ft-lbs

Stroke at rated energy (fuel setting 4)
11.81 feet

Energy at fuel setting 3
231450 ft-lbs

Energy at fuel setting 2
209755 ft-lbs

Energy at fuel setting 1
188050 ft-lbs

Energy at maximum stroke
330760 ft-lbs

Maximum geometric stroke
15 feet

Blows per minute
35-45 .

Weights
- -

Bare hammer with trip
43025 lbs

Hammer with box lead guides
45325 lbs

Drive cap base
DCB-3HD .

Drive cap base weight
2340 lbs

Striker plate
1410 lbs

Cushion material
192 lbs

Pile insert
DCC-24 .

Pile insert weight
1775 lbs

Operating weight with drive cap above
51042 lbs

Fuel tank
34 gal

Lube oil tank
11.4 gal

Dimensions
- -

Hammer length (L)
22 feet

Length with trip guides (GL)
25 feet

Length at max. stroke (OL)
30.6 feet

Overall width (W)
42 in

Standard box leads width (LW)
36 in

Overall depth
46 in

Centerline to rear (CR)
26 in

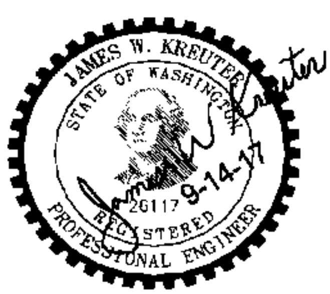
Centerline to front (CF)
19.5 in

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**



Rev B

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

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

Bubble Curtain Performance Calculations	Sheet: 4 of: 23

D. ASSUMPTIONS & CRITERIA

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

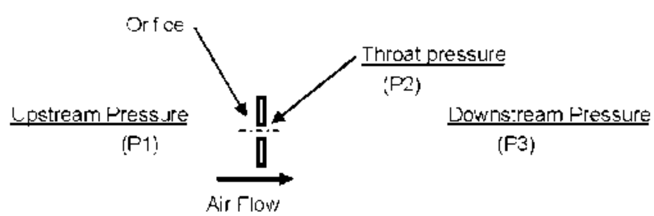
   SCFM = Air as measured at "standard" conditions (Temp = 60-F, 14.7-PSIA)

   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.



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

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

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

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.

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

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.

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

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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Bubble Curtain Performance Calculations | Sheet: 9 of: 23

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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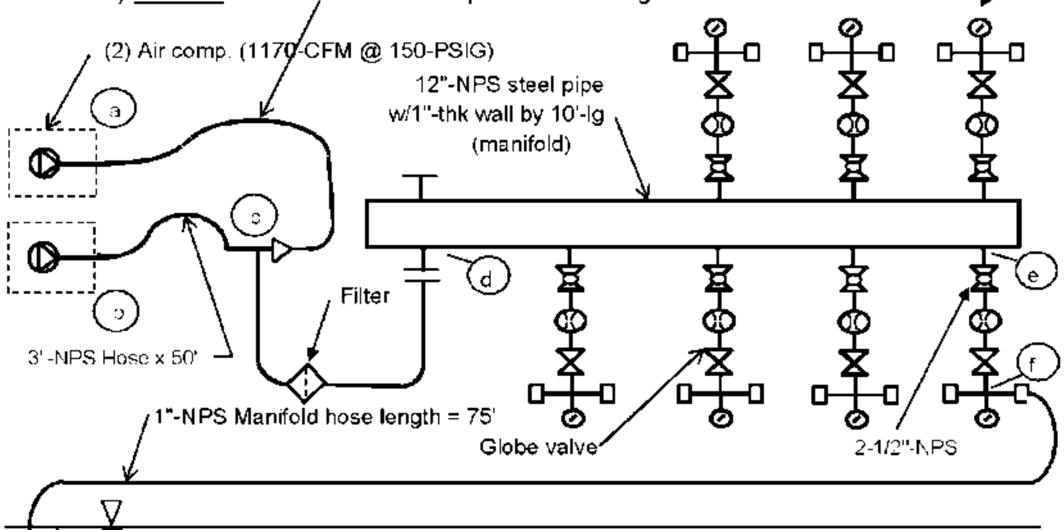
Bubble Curtain Performance Calculations	Sheet: 10 of: 23

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	

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

Bubble Curtain Performance Calculations Sheet: 11 of: 23

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

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

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.

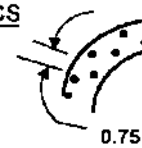
Project: **Colman Dock Project**	By: jwk	Date: 14-Sep-17 **REV B**

Bubble Curtain Performance Calculations	Sheet: 13 of: 23

I. UNCONFINED RING AIR FLOWRATE CALCS

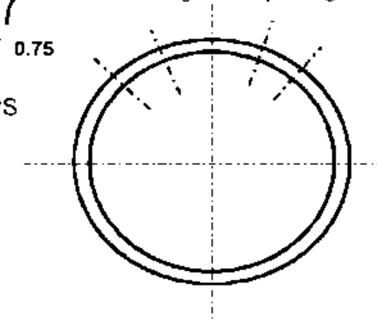
50-FT Depth

(4) holes every 3/4" of length

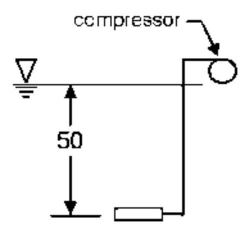


Bubbler ring hole spacing

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	=	0.063	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

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

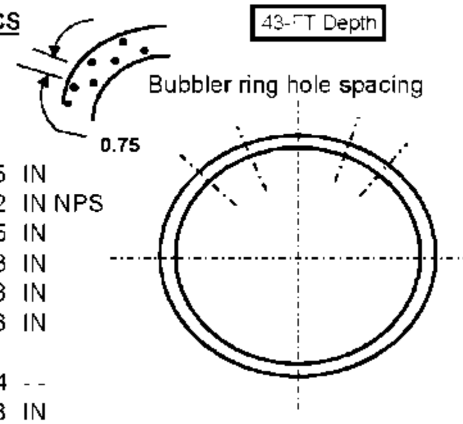
Bubble Curtain Performance Calculations | Sheet: 14 of: 23

I. UNCONFINED RING AIR FLOWRATE CALCS

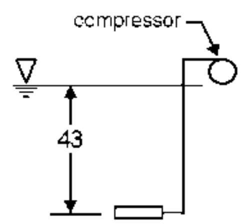
43-FT Depth

(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

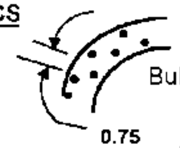
Flow rate per foot of ring	=	32.9	SCFM > 32.91-SCFM

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

Bubble Curtain Performance Calculations	Sheet: 15 of: 23

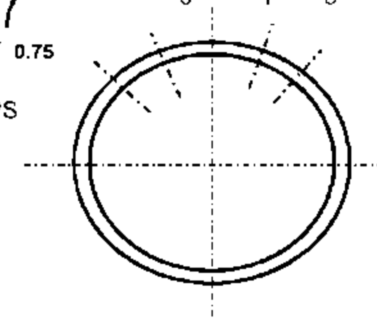
I. UNCONFINED RING AIR FLOWRATE CALCS

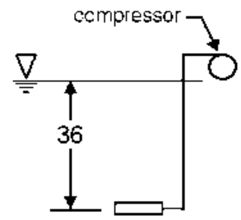
36-FT Depth



(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	=	**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

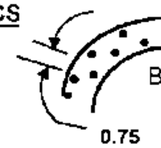
Flow rate per foot of ring	=	33.1	SCFM > 32.91-SCFM

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

Bubble Curtain Performance Calculations	Sheet: 16 of: 23

I. UNCONFINED RING AIR FLOWRATE CALCS

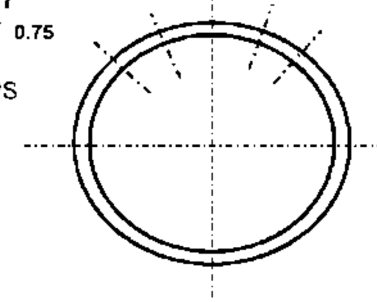
29-FT Depth



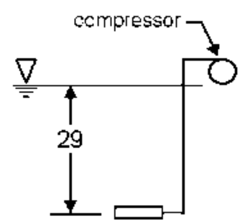
(4) holes every 3/4" of length

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	=	**0.14200**	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**

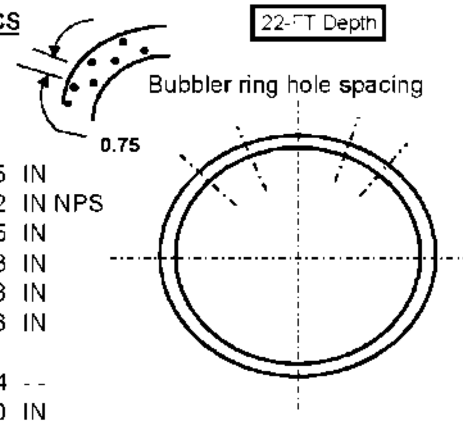
Bubble Curtain Performance Calculations | Sheet: 17 of: 23

I. UNCONFINED RING AIR FLOWRATE CALCS

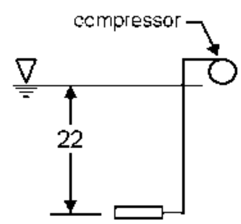
22-FT Depth

(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

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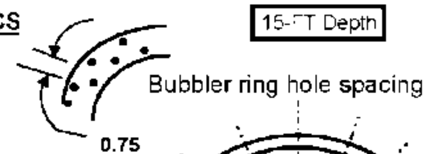
Bubble Curtain Performance Calculations | Sheet: 18 of: 23

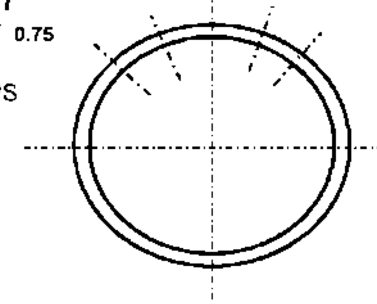
I. UNCONFINED RING AIR FLOWRATE CALCS

15-FT Depth

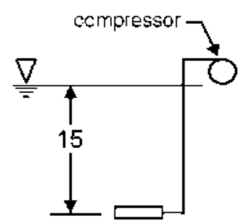


(4) holes every 3/4" of length

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

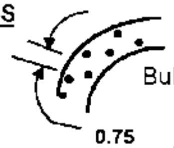
Flow rate per foot of ring	=	33.1	SCFM > 32.91-SCFM

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

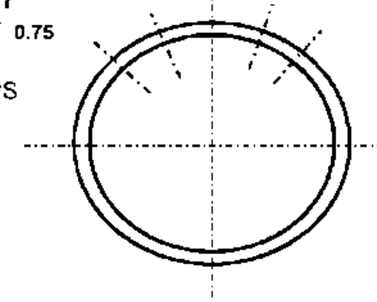
8-FT Depth



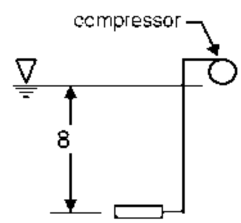
(4) holes every 3/4" of length

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	=	**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**

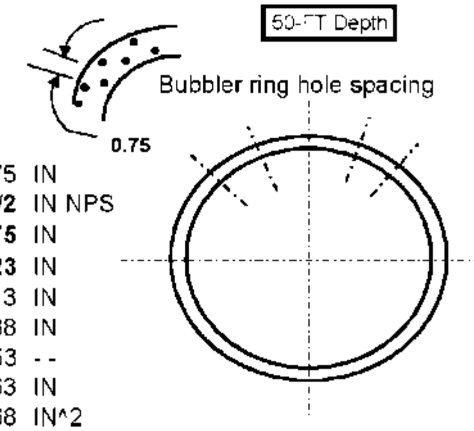
Bubble Curtain Performance Calculations | Sheet: 20 of: 23

J. CONFINED RING AIR FLOWRATE CALCS

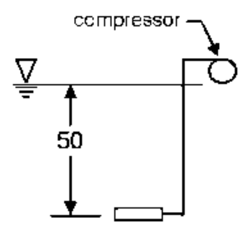
50-FT Depth

(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

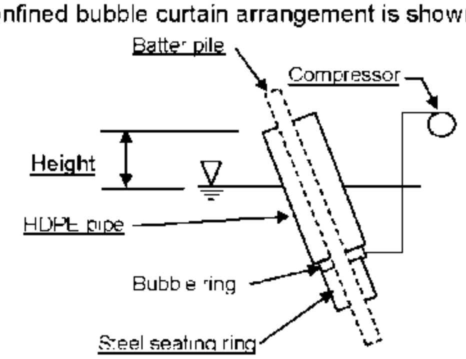
Project: **Colman Dock Project** | By: jwk | Date: 14-Sep-17 **REV B**

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-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)

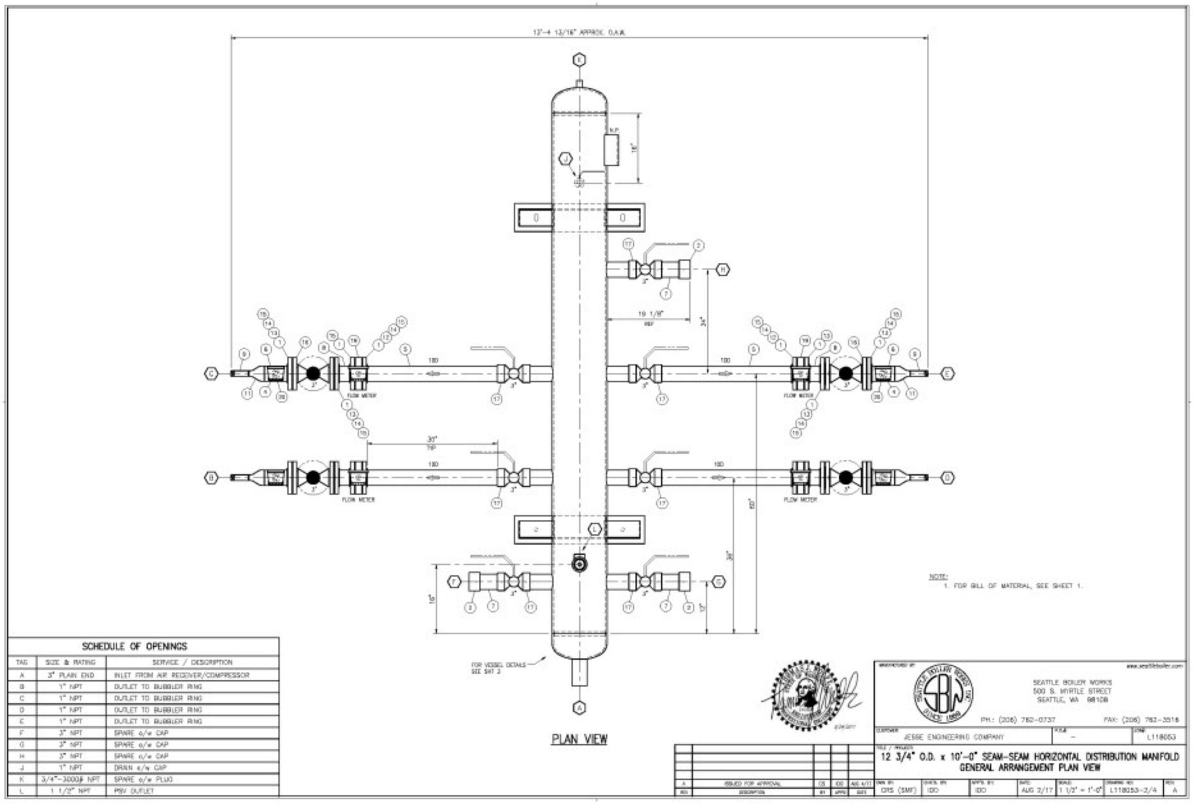
3) Behavior of air & water in confinement tube — 72"-DIA.

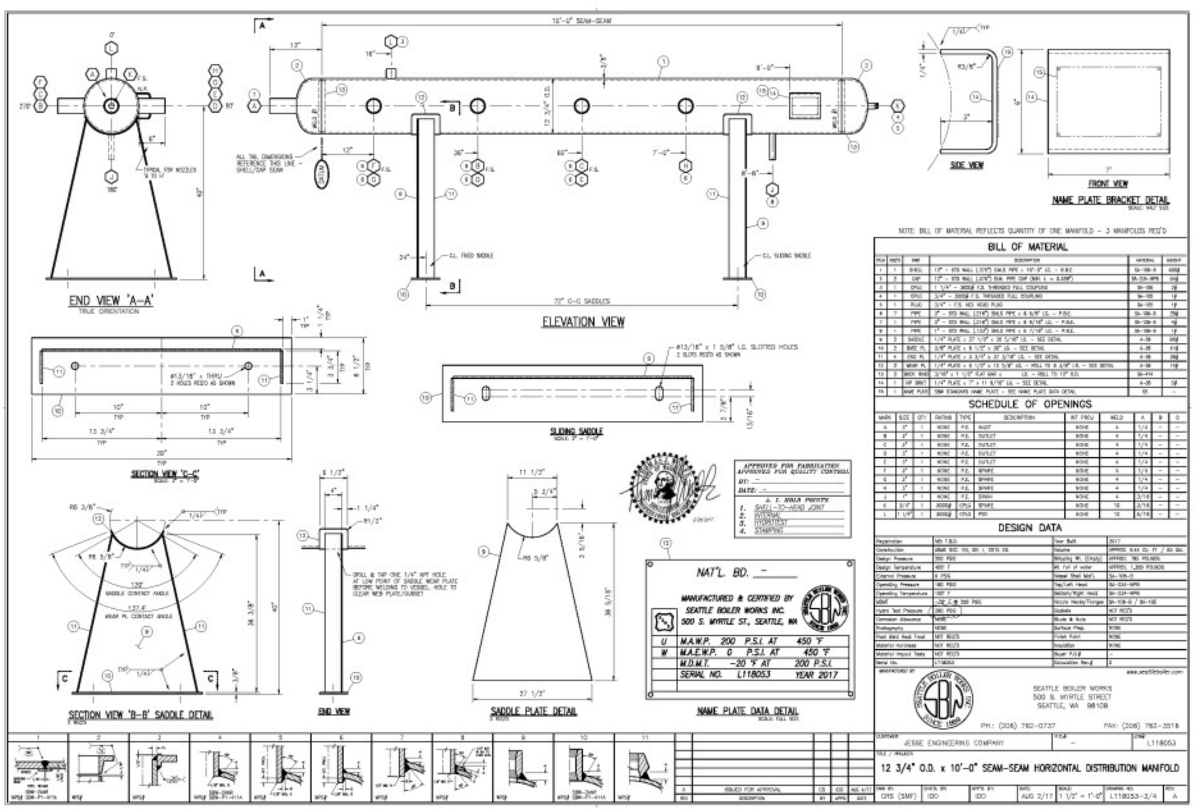
Pumping rate	=	**0.01**	GAL/DAY
Pipe diameter	=	**72.00**	IN
Submergence	=	**50.0**	FT
Lift	=	**0.5**	FT
cross-sectional area of pipe	=	28.274	FT^2
Pipe volume	=	1,427.85	FT^3
Pipe volume	=	7.48	GAL/FT^3
Vl (Flow rate)	=	0	GPM
A (Pipe area)	=	28.274	FT^2
L (Lift)	=	0.5	FT
D (Pipe diameter)	=	72	IN
Lf (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

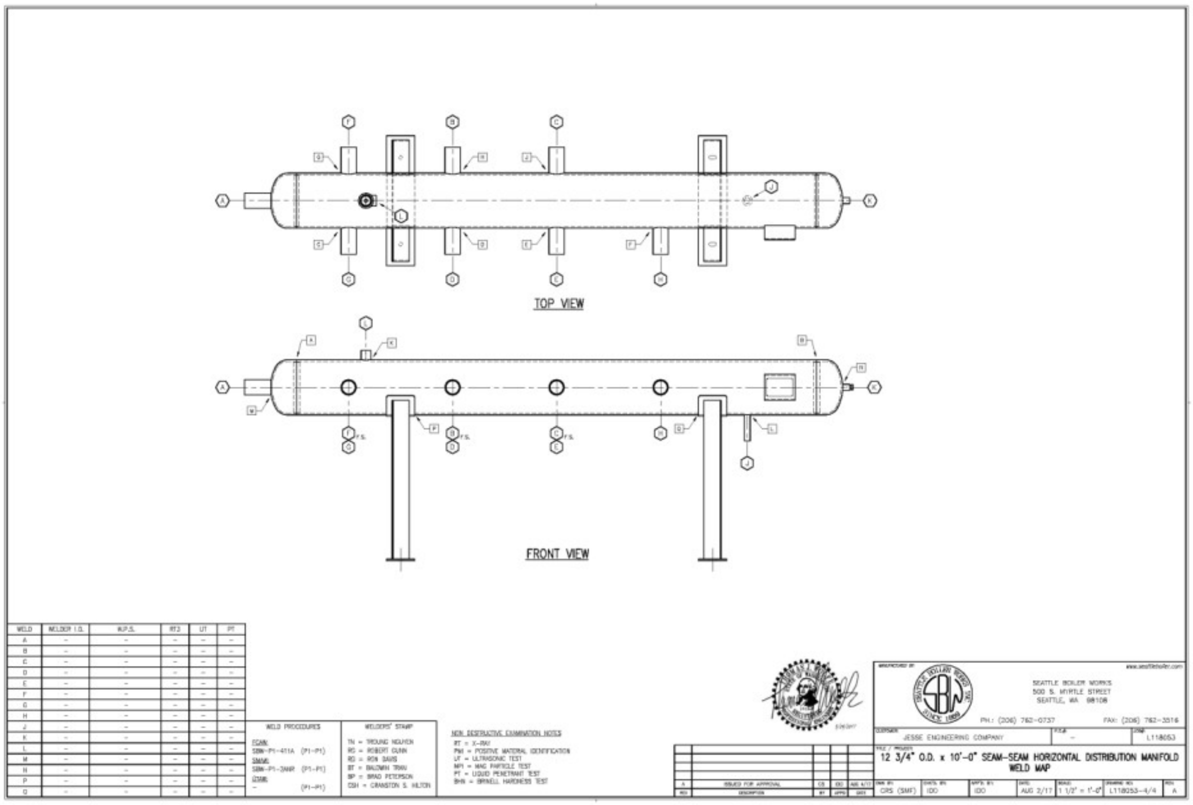
NOTE: This calculation shows that at a flowrate of 709-CFM and a tube length extending 0.5-FT (6-IN) MINIMUM above the surface, water will begin pumping out of the top of the HDPE tube.

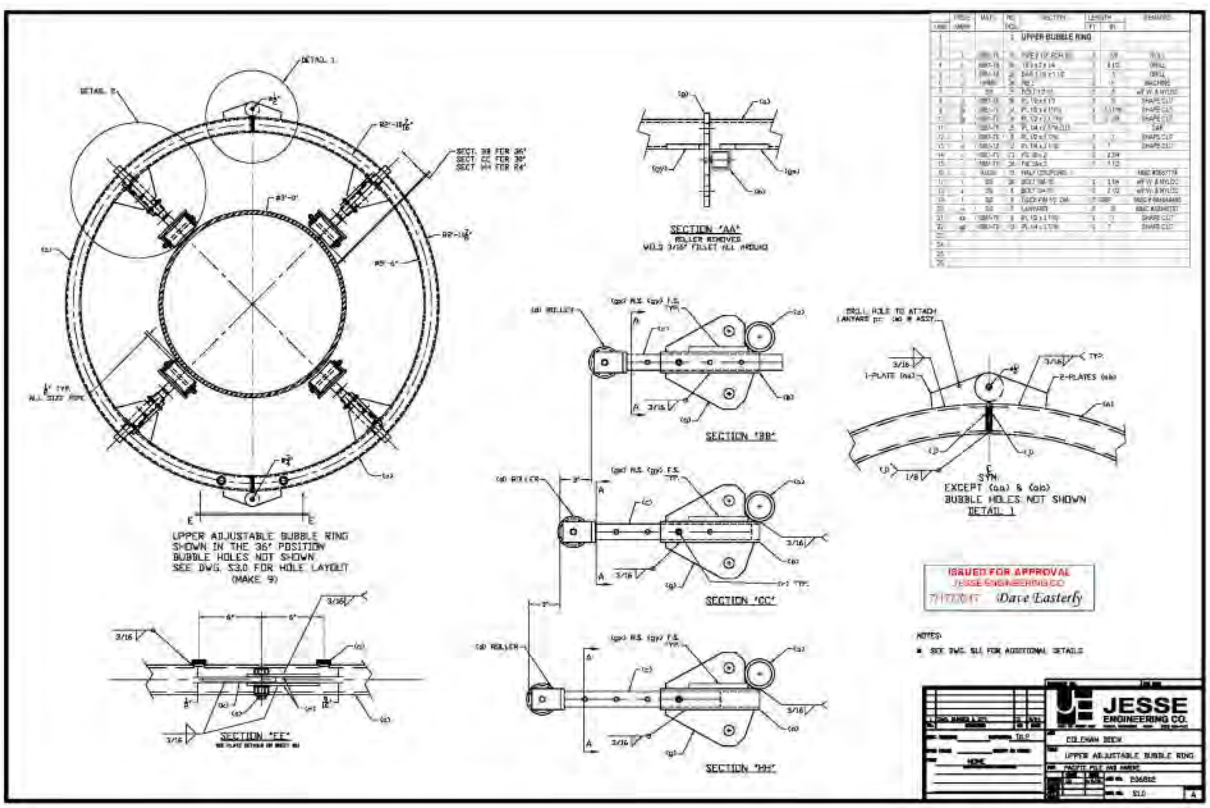
For the required air flowrate of 551-CFM (calculated in earlier calc.) the water will stay in the tube.

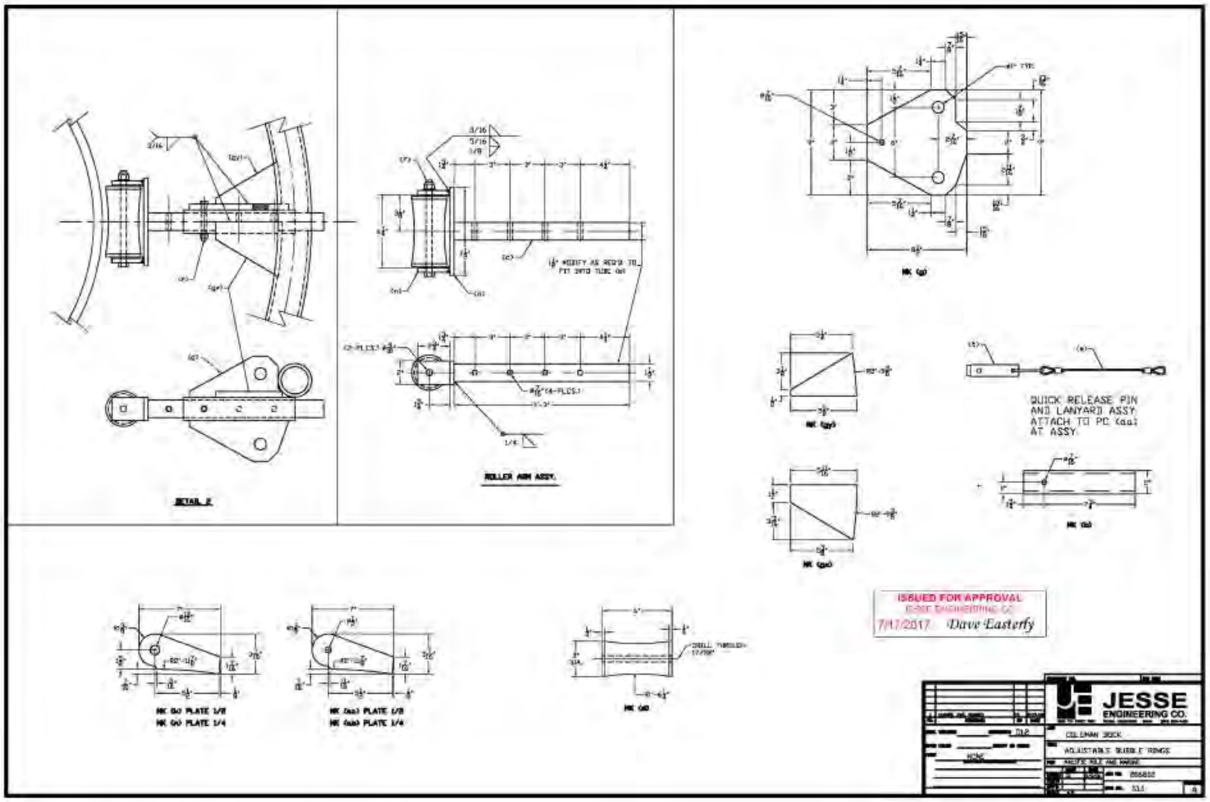
Project: **Colman Dock Project** | By: jwk | Date: 14-Sep-17 **REV B**

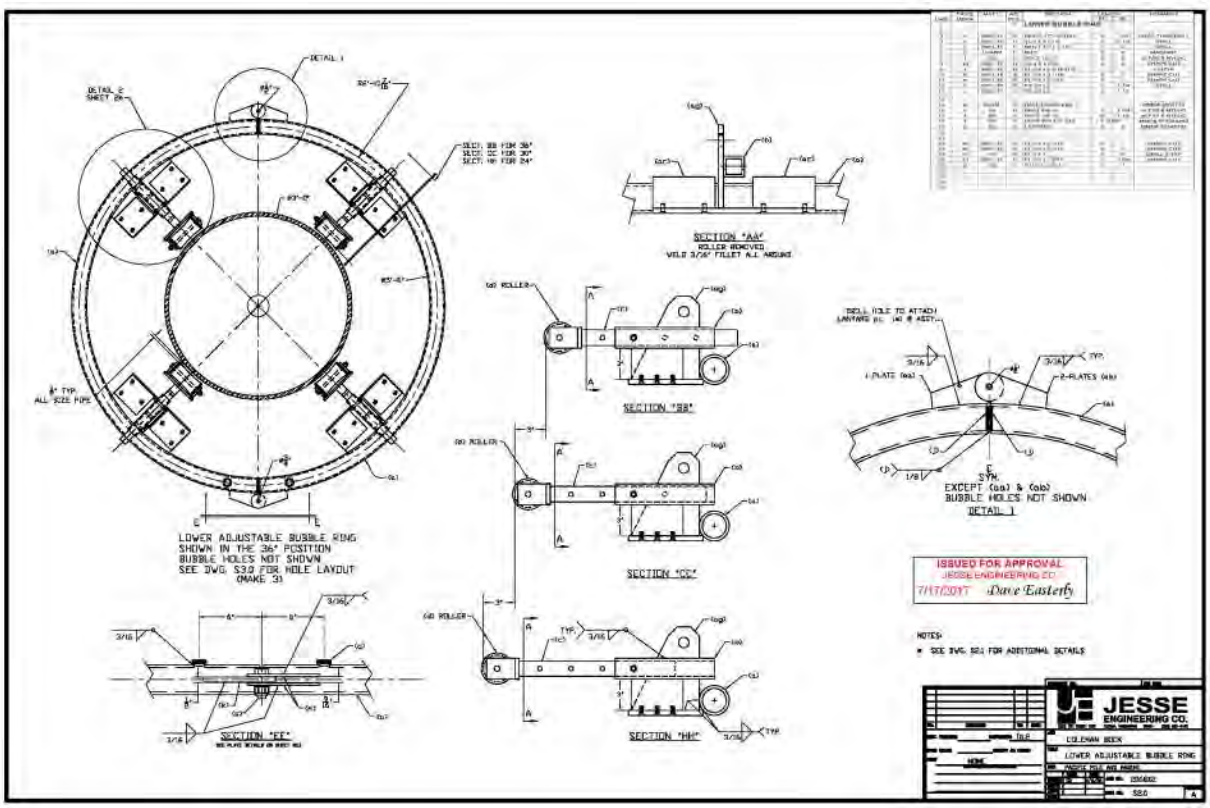

PLAN VIEW
SCHEDULE OF OPENINGS
SEATTLE BOILER WORKS
JESSE ENGINEERING COMPANY
12 3/4" O.D. x 10'-0" SEAM-SEAM HORIZONTAL DISTRIBUTION MANIFOLD
GENERAL ARRANGEMENT PLAN VIEW

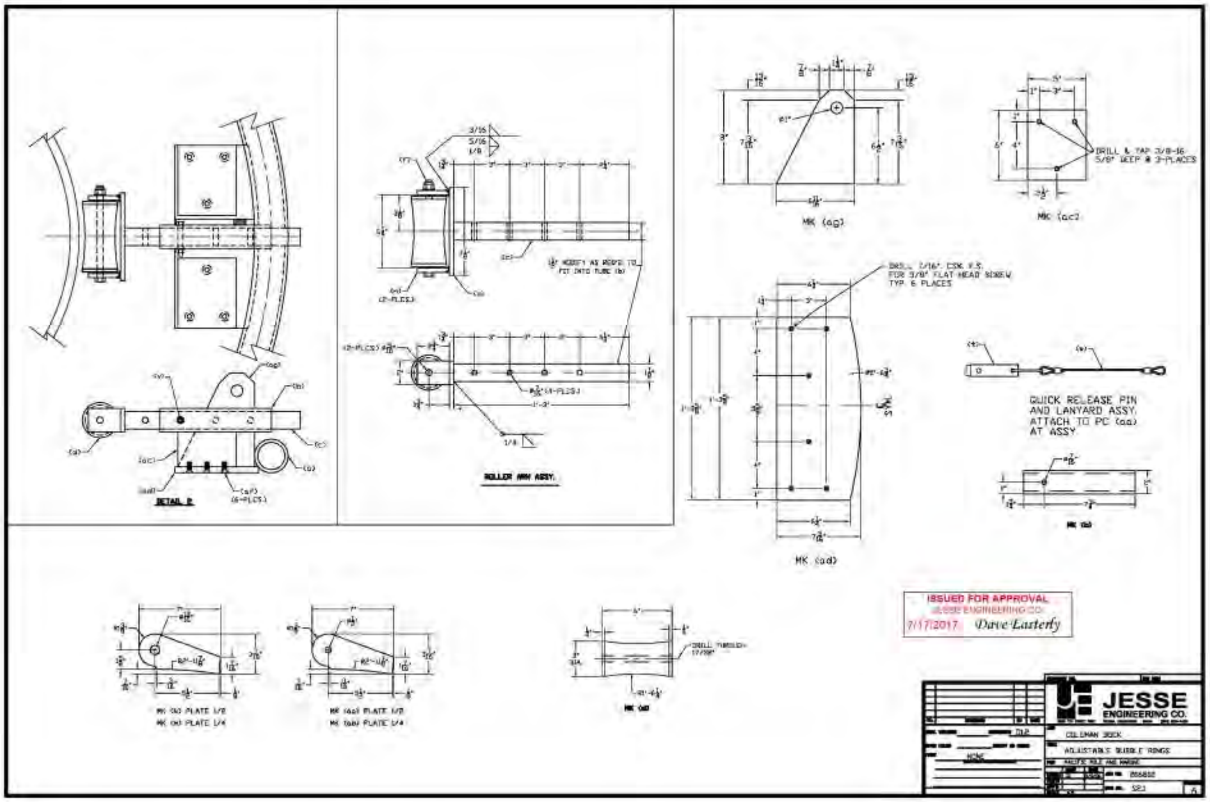

END VIEW 'A-A'
ELEVATION VIEW
BILL OF MATERIAL
SCHEDULE OF OPENINGS
DESIGN DATA
SECTION VIEW 'B-B' SADDLE DETAIL
END VIEW
SADDLE PLATE DETAIL
NAME PLATE DATA DETAIL
SEATTLE BOILER WORKS
JESSE ENGINEERING COMPANY
12 3/4" O.D. x 10'-0" SEAM-SEAM HORIZONTAL DISTRIBUTION MANIFOLD

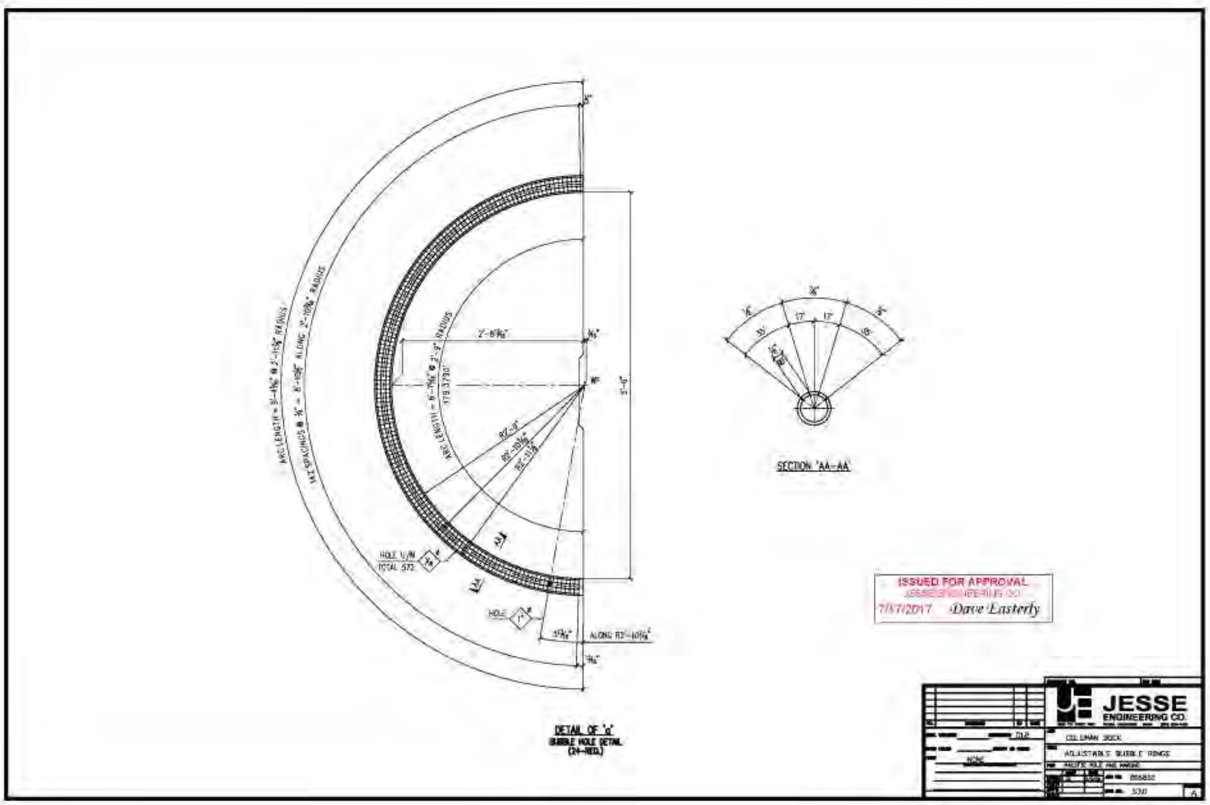

TOP VIEW
FRONT VIEW
SEATTLE BOILER WORKS
500 S. MYRTLE STREET
SEATTLE, WA 98108
JESSE ENGINEERING COMPANY
12 3/4" O.D. x 10'-0" SEAM-SEAM HORIZONTAL DISTRIBUTION MANIFOLD
WELD MAP


UPPER ADJUSTABLE BUBBLE RING
SHOWN IN THE 36' POSITION
BUBBLE HOLES NOT SHOWN
SEE DWG. S3.0 FOR HOLE LAYOUT
(MAKE 9)
SECTION "AA"
SECTION "BB"
SECTION "CC"
SECTION "HH"
SECTION "EE"
DETAIL 1
EXCEPT (aa) & (ab)
BUBBLE HOLES NOT SHOWN
ISSUED FOR APPROVAL
JESSE ENGINEERING CO
Dave Easterly
JESSE ENGINEERING CO.
COLMAN DOCK
UPPER ADJUSTABLE BUBBLE RING


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


SECTION "AA"
ROLLER REMOVED
WELD 3/16" FILLET ALL AROUND
SECTION "BB"
SECTION "CC"
SECTION "EE"
SECTION "HH"
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
DETAIL 1
ISSUED FOR APPROVAL
7/17/2017 Dave Easterly
NOTES:
JESSE ENGINEERING CO.
LOWER ADJUSTABLE BUBBLE RING


DETAIL 2
ROLLER ARM ASSY.
MK (ag)
MK (ac)
MK (ad)
MK (aa)
QUICK RELEASE PIN AND LANYARD ASSY. ATTACH TO PC (aa) AT ASSY.
ISSUED FOR APPROVAL
7/17/2017 Dave Easterly
JESSE ENGINEERING CO.
COLMAN DOCK
ADJUSTABLE BUBBLE RINGS


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