Port of Alaska Modernization Program Petroleum and Cement Terminal Phase 2 Hydroacoustic Monitoring Report

Prepared for

Port of Alaska

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Acronyms and Abbreviations

µPa	microPascal
APE	American Piledriving Equipment
C/MU	coulombs/mechanical unit
dB	decibel(s)
dB re 1 µPa	dB referenced to a pressure of 1 microPascal
ft^3	cubic feet
Hz	Hertz
IHA	Incidental Harassment Authorization
kHz	kilohertz
km	kilometer(s)
L_{eq}	equivalent sound level
L_{pk}	peak sound pressure level
m^3	cubic meter(s)
mi	mile(s)
MMPA	Marine Mammal Protection Act
mV/pC	microvolts per picocoulombs
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PAMP	Port of Alaska Modernization Program
PCT	Petroleum and Cement Terminal
POA	Port of Alaska
RMS	root mean square
SEL	sound exposure level
SEL_{cum}	cumulative sound exposure level
SFD	South Floating Dock
SLM	Sound Level Meter(s)
SPL	sound pressure level
SSV	sound source verification
TL	transmission loss
V	volts
V/pC	volts per picocoulombs
Vt	volume of air per layer

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Executive Summary

This report provides results of hydroacoustic monitoring conducted during the 2021 in-water construction season at the Port of Alaska (POA) in Anchorage, Alaska. The POA is modernizing its facilities through the Port of Alaska Modernization Program. Located within the Municipality of Anchorage on Knik Arm in upper Cook Inlet, the existing infrastructure and support facilities were constructed largely in the 1960s. They are substantially past their design life, have degraded to levels of marginal safety, and are in many cases functionally obsolete, especially with regards to seismic design criteria and condition.

Pile driving during the first season of the Petroleum and Cement Terminal Project began in April 2020 and continued into the fall, with the first bout of hydroacoustic monitoring occurring in June 2020. The second season of the project started in April 2021, with hydroacoustic monitoring occurring in May 2021. Measurements were made between 10 and 30 meters from the location of each active pile since access to the construction sites, configuration of structures, and strong tidal conditions made consistent measurements at 10 meters difficult. Measurements were also made from bottom-anchored moorings at the 600- to 770-meter range, at about 2,700 meters and at about 6,000 meters to compute transmission loss and distances to the Level A and Level B harassment zones, as implemented by the National Marine Fisheries Service under the Marine Mammal Protection Act. Measurements were conducted for the following pile installation activities:

1. Vibratory installation of fourteen 36-inch template piles (attenuated with an air bubble curtain)
2. Vibratory shaking[1] of one 144-inch mooring dolphin pile (attenuated with an air bubble curtain)
3. Vibratory installation of one 144-inch mooring dolphin pile (attenuated with an air bubble curtain)
4. Impact pile driving of two 144-inch mooring dolphin piles (attenuated with an air bubble curtain)

<u>Summary of Acoustic Data – Vibratory Installation of Attenuated 36-inch Template Piles</u>

Sound pressure level (SPL) in decibels (dB) referenced to a pressure of 1 microPascal (dB re 1 µPa) were based on the median of the root mean square (RMS) sound level pressures for each pile driving event. Vibratory SPLs were based on 1-minute RMS values, while impact pile driving SPLs were based on RMS measured over the pulse durations. The pulse sound exposure level (SEL) is expressed in dB referenced to a pressure of 1 microPascal squared per second (dB re 1 $\mu Pa^2 sec$) is the accumulated sound energy for each pulse. Peak pressures in dB referenced to a pressure of 1 dB re 1 µPa are the maximum of the absolute value of the pressure measured over a pulse. The accumulated SELs for all piling events were computed to assess Level A harassment (based on potential permanent hearing threshold or PTS). The median SPL (or RMS) was computed for vibratory piling events. For impact pile driving, median peak pressure, SPL (or RMS), and SEL for each pulse are reported. The overall transmission loss (TL) coefficient, assuming a Log_{10} falloff rate, and source level were computed from a regression of sound measurements at varying distances for each pile. The TLs along with the source level were used to compute 10-meter level. These levels were also used to compute the extent of the Level B Harassment zones.

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[1] The vibratory shaking event was atypical and not representative of vibratory driving because the vibratory hammer did not attach to the pile correctly. Several attempts were made to resolve the issue, but each time the hammer was engaged, the pile rattled loudly; throughout the report this event is referred to as “vibratory shaking”.

Table ES1. Summary of underwater sound measurements[a]

Pile Type	Sound Type	10-m Level (dB)	TL (Log_{10} coefficient)	Extent of Level B Zone (km)
Vibrate 36-inch temporary trestle with air bubble curtain	RMS	160	12.2	6 to 11.8 [b]
Vibratory "shaking" of 144-inch pile with air bubble curtain (MD5)	RMS	175	16.0	19.7
Vibrate 144-inch pile with air bubble curtain (MD6)	RMS	153	14.1	1.5[c]
Impact 144-inch mooring dolphin pile with air bubble curtain	RMS	207	19.6	2.6
	Peak	219	20.1	--
	SEL	193	18.3	--

[a] The 10-m levels and TL coefficients were modeled based on measured sound levels.

[b] Measurements only made out to 2.8 kilometers across Cook Inlet.

[c] Detectable measurements only out to 115 meters.

Note: dB = decibels; km = kilometers; m = meters; RMS = root mean square; SEL = sound exposure level; TL = transmission loss.

Extent of Level A and B Harassment Zones

Table ES2 summarizes the average extent of zones used to assess Level A and Level B harassment for each size of pile during vibratory installation and impact driving. Table ES2 address only the accumulated SEL thresholds to assess Level A and RMS levels to assess Level B harassment. The highest measured peak sound pressures for impact driving sounds were below the thresholds for all of the hearing groups except thresholds used for Level A harassment to high-frequency cetaceans. The computed mean of the peak sound pressures for impact pile driving at 10 meters was 219 dB. Using the computed transmission loss from the average median source level and regression for the entire data set, levels above 202 dB extended out to 70 meters. However, when evaluated using individual measurements, the zone was 110 meters for one pile driving event with a measurement of 202 dB. Note that Level A harassment for high-frequency cetaceans extended well beyond that distance due to accumulation of sound (SEL sound levels), as shown in Table ES2. To assess Level B harassment, the ambient sound level of 122.2 dB that was measured in 2016 was used (Austin et al. 2016).

Table ES2. Average estimated distances of the Level A and Level B harassment zones during vibratory installation and impact pile driving using 2021 PCT data

Type / Size of Pile	Species Hearing Group	Level A		Level B	
		Threshold (dB SEL)	Distance (m)	Threshold (dB RMS)	Distance (km)
Vibrate 36-inch temporary trestle with air bubble curtain	Low-Frequency Cetaceans (e.g., humpback whale)	199	1	122.2	11.8
	Mid-Frequency Cetaceans (e.g., beluga whale)	198	<1		
	High-Frequency Cetaceans (e.g., harbor porpoise)	173	1		
	Phocids (e.g., harbor seal)	201	<1		
	Otariids (e.g., sea lion)	219	1		
Vibratory "shaking" of 144-inch pile with air bubble curtain (MD5)	Low-Frequency Cetaceans	199	2	122.2	19.7
	Mid-Frequency Cetaceans	198	<1		
	High-Frequency Cetaceans	173	<1		
	Phocids	201	<1		
	Otariids	219	<1		
Vibrate 144-inch pile with air bubble curtain (MD6)	Low-Frequency Cetaceans	199	<1	122.2	1.5
	Mid-Frequency Cetaceans	198	<1		
	High-Frequency Cetaceans	173	<1		
	Phocids	201	<1		
	Otariids	219	<1		
Impact 144-inch mooring dolphin pile (attenuated)	Low-Frequency Cetaceans	183	4,349	160	2.6
	Mid-Frequency Cetaceans	185	34		
	High-Frequency Cetaceans	155	1,288		
	Phocids	185	603		
	Otariids	203	51		

Note: dB = decibel(s); km = kilometer(s); m = meter(s); RMS = root mean square; SEL = sound exposure level.

In Table ES3, the extent of Level A and Level B harassment zones based on 2021 data were compared to those predicted for the Petroleum and Cement Terminal (PCT) Incidental Harassment Authorization (IHA) in the *Port of Alaska Modernization Program, Petroleum and Cement Terminal Project: Application for a Marine Mammal Protection Act Incidental Harassment Authorization* (POA 2019). For measured vibratory sounds, the extent of the Level B zones is based on the outermost measurement point that is relatively close to the pile. These estimates assume that the TL computed from the relatively small set of close-in measurements represents sound transmission across relatively large distances that are much farther than the measurement positions. Sound levels for vibratory driving could not be measured at levels beyond 2.8 kilometers (km) or below about 130 dB due to high noise levels caused by tidal currents.

Table ES3. Comparison of predicted and revised estimated distances of the Level A and Level B harassment zones

		Level A			Level B		
Type/Size of Pile	**Species Hearing Group**	**Predicted Distance (m)**	**Mean Number of Strikes or Minutes of Vibratory Pile Driving for Predicted Distance**	**Measured Distance (m)**	**Predicted Distance (km)**	**Distance (km; Estimated using 2021 Data)**	**Estimated Distance using 15Log$_{10}$ (km)**
Vibrate 36-inch temporary trestle with air bubble curtain	Low-Frequency Cetaceans (e.g., humpback whale)	12	75 minutes	1	1.699 original IHA 4.106 adjusted IHA[b]	11.8 using all points 6.6 using far-field points[a]	3.3
	Mid-Frequency Cetaceans (e.g., beluga whale)	1		<1			
	High-Frequency Cetaceans (e.g., harbor porpoise)	17		1			
	Phocids (e.g., harbor seal)	8		<1			
	Otariids (e.g., sea lion)	1		1			
Vibratory "shaking" of 144-inch pile with air bubble curtain (MD5) About one Minute duration	Low-Frequency Cetaceans	Not predicted	Not predicted	2	Not predicted	19.7	33.1
	Mid-Frequency Cetaceans			<1			
	High-Frequency Cetaceans			<1			
	Phocids			<1			
	Otariids			<1			
Vibrate 144-inch pile with air bubble curtain (MD6)	Low-Frequency Cetaceans	24	45 minutes	<1	9.069 original IHA 18 adjusted IHA[b]	1.5	1.1
	Mid-Frequency Cetaceans	3		<1			
	High-Frequency Cetaceans	34		<1			
	Phocids	15		<1			
	Otariids	1		<1			

Type/Size of Pile	Species Hearing Group	Level A			Level B		
		Predicted Distance (m)	Mean Number of Strikes or Minutes of Vibratory Pile Driving for Predicted Distance	Measured Distance (m)	Predicted Distance (km)	Distance (km; Estimated using 2021 Data)	Estimated Distance using 15Log10 (km)
Impact 144-inch mooring dolphin pile (attenuated)	Low-Frequency Cetaceans	3,781	5,000 strikes	4,349	1.946 original IHA 6.309 adjusted IHA[b]	2.6	13.6
	Mid-Frequency Cetaceans	194		34			
	High-Frequency Cetaceans	4,418		1,288			
	Phocids	2,167		603			
	Otariids	210		51			

[a] The far-field points consist of one measurement at 72 m from the pile, and the rest at more than 500 m from the pile.

[b] NMFS. 2021. Letter from Jolie Harrison, Chief of the Permits and Conservation Division, NMFS, to Sharen Wash, Deputy Director for the Port of Alaska, modifying the Cook Inlet beluga whale Level B harassment zone sizes and shutdown zone sizes for the Port of Alaska Modernization Program, Petroleum and Cement Terminal Project. Dated May 6, 2021.

Note: km = kilometers; m = meters.

Air Bubble Curtain Performance

The multi-ring air bubble curtain was in operation for all piling events measured. Since there was no air bubble curtain on-and-off operation, it is not possible to measure the effectiveness of the system in reducing sound levels. Indications of air bubble curtain performance in reducing sound are made by comparing measured sound levels against unattenuated levels predicted in the IHA.

Measurements for 36-inch-diameter template piles installed with a vibratory driver indicate that RMS sound levels at 10 meters from the pile are 8 dB lower than predicted for unattenuated conditions at 160 dB at 10 m from the pile. The rate of sound transmission was less, resulting in levels that were higher than predicted at the far distances. This indicates that the air bubble curtain was effective only in reducing sounds near the pile.

There were only short measurements of piling using a vibratory driver for the 144-inch-diameter piles when the air bubble curtain system was operating. One event was atypical and not representative of vibratory driving when the vibratory hammer did not attach to the pile correctly. Several attempts were made to resolve the issue, but each time the hammer was engaged, the pile rattled loudly. Finally, the attempt to drive the pile was abandoned. Measured sound levels from typical vibratory driving with the air bubble curtain were 18 dB lower than anticipated. The lower measured sound level is likely a combination of air bubble curtain performance and lower sound generation by the activity.

Impact driving produced sound levels that were about 5 dB lower than predicted unattenuated levels. Impact pile driving produced measurable sound well above background over the frequency range of about 12.5 to 2,500 Hertz (Hz) throughout all measurement positions out to 6 km. Since the 144-inch-diameter pile sound levels were developed from theoretical data using sounds from other pile sizes, it is not possible to make an accurate comparison to unattenuated conditions.

Difficulties Measuring Far-Field Sound

Conducting underwater sound measurements in Knik Arm is challenging due to the high current velocities. Strong currents cause flow effects that are an artefact of the measurement process itself, with water moving against the hydrophone and creating a source of noise that is not naturally present in the environment. Water flowing across the hydrophone is one effect and so is movement of the entire hydrophone system. Use of a flow shield around the hydrophone reduced but did not eliminate this effect, which resulted in elevated low-frequency sound, with greatest effects below 50–100 Hz. The overall sound levels reported consist of the 1/3-octave bands summed over the range of 20 to 20,000 Hz. The measurement of vibratory sounds was most affected, as much of the sound energy was in frequencies below 100 Hz. Measurements at 2,800 meters or further were usually not possible for vibratory pile driving due to strong currents that caused noise. Several attempts were made to measure these sounds at about 6 kilometers, but the sounds were not measurable above the high background levels that typically exceeded 130 dB. The high background levels did not affect impact pile driving measurements, as these sounds are typically above 100 Hz and mostly in the range of 200 to 500 Hz.

1 Introduction

The Port of Alaska (POA) is modernizing its facilities through the Port of Alaska Modernization Program (PAMP). Located within the Municipality of Anchorage on Knik Arm in upper Cook Inlet, the existing infrastructure and support facilities were constructed largely in the 1960s. They are substantially past their design life, have degraded to levels of marginal safety, and are in many cases functionally obsolete, especially with regards to seismic design criteria and condition. The PAMP will include construction of new pile-supported wharves and trestles, with a planned design life of 75 years.

When completed, the Petroleum and Cement Terminal (PCT) will be a new pile-supported structure located along the southern shoreline of the POA (Figure 1-1). The PCT Project involves construction of the terminal platform, access trestle, and mooring and breasting dolphins; and installation of utility (electricity, water, and communication), petroleum, and cement lines linking the terminal and shore (Figure 1-2). The PCT Project pile driving is being conducted over two construction seasons. The first season started in April 2020 and was completed in October 2020; the second season started in May 2021, and the removal of the 36-inch temporary piles was completed in September.

Results of the hydroacoustic monitoring conducted for Phase 1 in 2020 were reported in January 2021 (Reyff et al. 2021). Those monitoring results included vibratory pile installation of temporary trestle piles that were 24 and 36 inches in diameter, vibratory installation of temporary template piles that were 24 inches in diameter, vibratory stabbing[2] of 48-inch-diameter permanent trestle and platform piles, impact driving of 48-inch-diameter piles and vibratory stabbing of 72-inch-diameter air bubble casings. The Phase 1 report was later amended with an appendix of results from monitoring the vibratory removal of the 24- and 36-inch-diameter temporary trestle piles to further evaluate the effectiveness of the confined air bubble noise attenuation system.

Phase 2 of the PCT Project included vibratory installation of 36-inch-diameter temporary trestle piles and installation of the 144-inch-diameter breasting and mooring dolphin piles. This report summarizes the methods and equipment used, as well as the results, for underwater hydroacoustic monitoring completed during pile driving operations in May 2021 for Phase 2 of the PCT construction project. Data collection and analysis methods were consistent with National Marine Fisheries Service (NMFS) guidance on hydroacoustic monitoring for near-source measurements.

Sound levels are described in decibels (dB), referenced to 1 microPascal (re 1µPa) for peak and root-mean-square (RMS) sound pressure levels (SPLs) and re 1µPa^2-sec for sound exposure levels (SELs).

[2] A vibratory driver was used to initially install the pile so it is plumb and set. The vibratory driver allows the Contractor to carefully control the rate of penetration and make adjustments for ensuring that the pile meets the survey requirements. This process is sometimes referred to as stabbing the pile.

Figure 1-1. Location of the PCT Project in Knik Arm

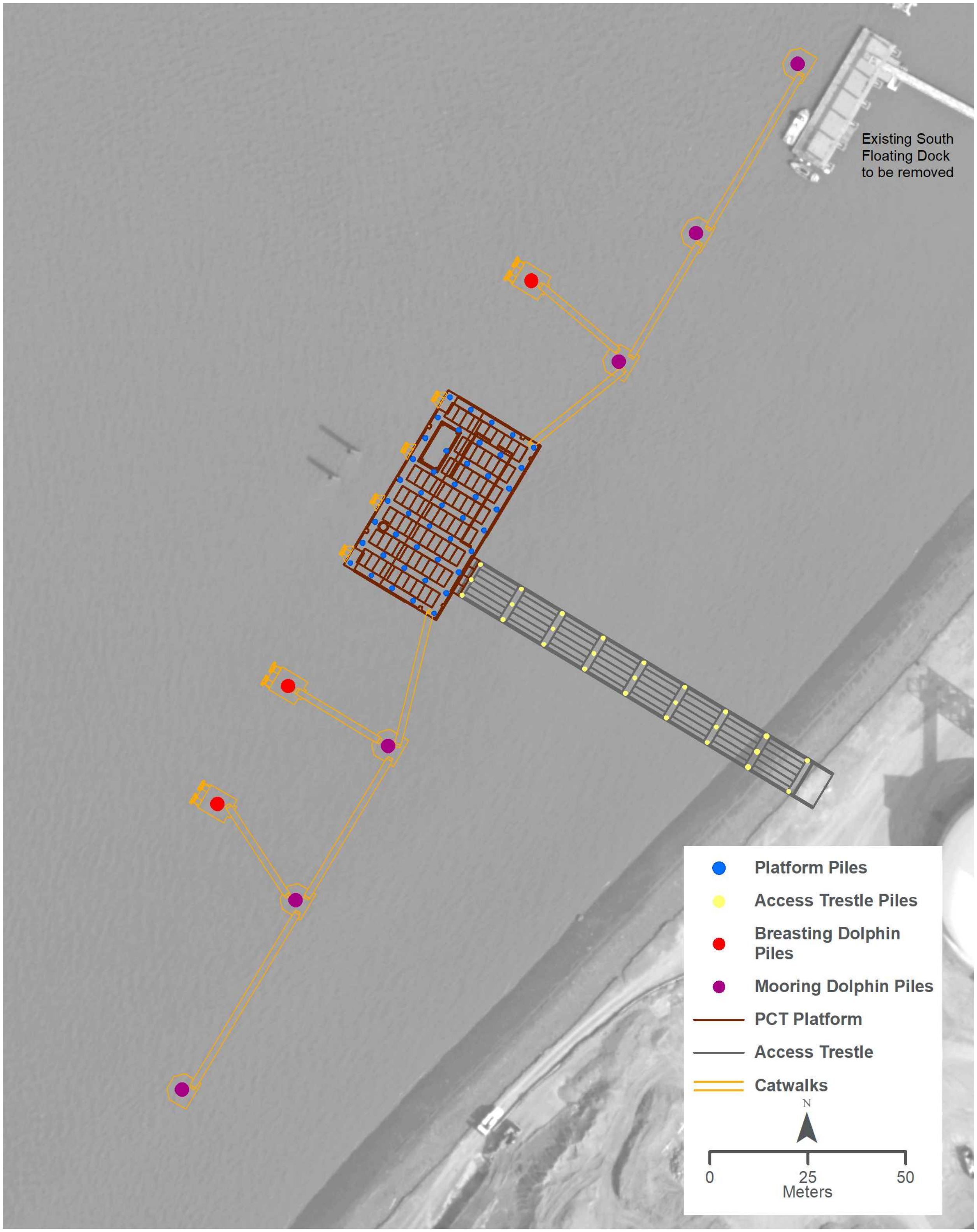

Figure 1-2. Project footprint and pile locations for the proposed PCT (both seasons; only the access trestle and platform piles were driven during 2020)

1.1 Project Description

The PCT terminal trestle and platform were constructed in 2020. The first round of hydroacoustic monitoring during 2020 pile installation was completed on June 25, 2020. Vibratory pile driving monitoring was completed for eight 24-inch-diameter events, five 36-inch-diameter events, and twelve 48-inch pile events. All events were measured when an air bubble casing system was operating, with the exception of one 48-inch pile that had to be installed using a special pile guide. Measurements for impact driving were conducted for eleven 48-inch piles plus the restrike of two piles. Additionally, the installations of four 72-inch-diameter air bubble casings and the removal of one 36-inch pin pile were measured.

This study addresses the remaining in-water construction, which involved the installation of large monopiles that serve as mooring and breasting dolphins. The six mooring dolphins and three breasting dolphins each consist of a single round, 144-inch-diameter steel pipe pile. Mooring dolphins were constructed parallel to and landward of the loading platform face, and breasting dolphins were constructed parallel to and landward of the PCT loading platform face. An APE 600 vibratory driver was typically used to stab the pile through the template to achieve enough penetration in the substrate so the pile could be properly supported by the template prior to impact pile driving. An IHC S-800 (with a P1800 power pack) hydraulic impact hammer was used to drive the piles to their tip elevation. The dolphin piles were driven through a template that was supported by four 36-inch-diameter piles (Figure 1-3). The final design includes catwalks installed above the water to connect the dolphins and loading platform.

Figure 1-3. Installation of a 144-inch diameter mooring dolphin pile through template supported by 36-inch-diameter piles with air bubble curtain system operating in foreground

Temporary construction piles were needed during Phase 2 to anchor the template that guides the installation of 144-inch piles at each of the nine dolphin locations (Figure 1-4). The temporary piles were installed using an APE 300-6 vibratory hammer. Each 144-inch monopile required four temporary 36-inch plumb piles to secure the template in place. Impact pile driving for the temporary piles was not necessary (i.e., unknown obstructions were not encountered). The air bubble curtain was installed between the 144-inch pile and the 36-inch template piles. Intervening subsurface obstructions to the underwater sound field were piles and the hull of the construction barge.

Figure 1-4. Installation of a 36-inch-diameter temporary template pile with air bubble curtain system

1.2 Project Location and Physical Environment

Cook Inlet is a large tidal estuary that exchanges waters at its mouth with the Gulf of Alaska. Freshwater input to Cook Inlet comes from snowmelt and rivers, many of which are glacially fed and carry high sediment loads. The POA is located in the lower reaches of Knik Arm, in upper Cook Inlet, along the industrial waterfront of Anchorage, just south of Cairn Point and north of Ship Creek (Figure 1-1; Latitude 61° 15′ N, Longitude 149° 52′ W; Seward Meridian). Knik Arm and Turnagain Arm are the two branches of upper Cook Inlet, and Anchorage is located where the two branches join.

Knik Arm extends about 48 kilometers (km; 30 miles) in a north-northeasterly direction to the mouths of the Matanuska and Knik rivers. At Cairn Point, just northeast of the POA, Knik Arm narrows to about 2.4 km (1.5 miles) before widening to as much as 8 km (5 miles) at the tidal flats northwest of Eagle Bay at the mouth of Eagle River. The perpendicular distance to the west bank directly across Knik Arm from the POA is approximately 4.2 km (2.6 miles). The distance from the POA (east side) to nearby Port MacKenzie (west side) is approximately 4.9 km (3 miles).

Knik Arm is comprised of narrow channels flanked by large tidal flats that consist of fine, silt-sized glacial flour, sand, mud, and gravel. Approximately 60 percent of Knik Arm is exposed at Mean Lower Low Water. Surface waters in Knik Arm typically carry high silt and sediment loads, particularly during summer, making it an extremely silty, turbid waterbody with low visibility throughout the water column. The Matanuska and Knik rivers contribute the majority of fresh water and suspended sediment into the Knik Arm during summer. Smaller rivers and creeks also enter along the sides of Knik Arm.

Tides in Cook Inlet are semi-diurnal, with two unequal high and low tides per tidal day (tidal day = 24 hours, 50 minutes). Due to Knik Arm's predominantly shallow depths and narrow widths, tides near Anchorage are greater than those in the main body of Cook Inlet. The tides at the POA have a mean range of 7.99 meters (26.2 feet), and the maximum water level has been measured at more than 12.5 meters (41 feet) at the Anchorage station (National Oceanic and Atmospheric Administration [NOAA] 2015). Maximum current speeds in Knik Arm, observed during spring ebb tide, exceed 7 knots (12 feet per second). These tides result in strong currents in alternating directions through Knik Arm and a well-mixed water column. The navigation harbor at the POA is a dredged basin in the natural tidal flat. Natural sedimentation processes act to continuously infill the dredged basin throughout the year.

The POA is an active industrial port that is traversed by barges, tugboats, military vessels, and commercial vessels, including container ships, cruise ships, and tenders. The POA's shipping lanes and berths are subject to dredging in order to support port operations. These ongoing uses and activities contribute to elevated background levels of noise in and near the POA. In addition, upper Cook Inlet has some of the highest tides in the world (NOAA 2015), which create strong bidirectional currents and contribute to high ambient underwater sound levels. A number of hydroacoustic studies have measured ambient (background) noise levels in and near the POA that are variable and high (Blackwell 2005; URS 2007; Austin et al. 2016).

1.3 Monitoring Objectives

An acoustic monitoring plan for this project was submitted for the 2021 monitoring effort (HDR 2020). This plan was submitted as a portion of the *Application for a Marine Mammal Protection Act Incidental Harassment Authorization* (HDR 2019) Overall goals for the PCT Hydroacoustic Monitoring Plan during 2020 and 2021 are as follows:

- Measure SPLs at approximately 10 to 20 meters from the pile during pile installation to verify estimated sound source levels. Due to limited access to construction sites, air bubble curtain interference, configuration of structures, construction barge locations, and strong tidal currents, hydrophone positions were established generally at 10 to 31 meters from piles. Measurements could not be made at positions less than 19 to 31 meters for the 144-inch piles. An attempt to measure at 10 meters from each 36-inch-diameter pile was not possible for all pile driving events measured due to positioning of the construction barge and timing of acoustic monitoring events.
- Measure SPLs at approximately 300 to 1,000 meters from the pile to verify estimated distances to the Level A and Level B harassment zones. *A fixed mooring with a hydrophone that was 600 to 800 meters away was established for both 144-inch piles measured and seven of the 36-inch piles measured. This position was sometimes compromised by high background sounds due to strong tidal currents.*
- Measure SPLs at distances of approximately 3 km and 5 to 6 km from the pile to aid in estimation of transmission loss (TL) rates. *Fixed moorings with hydrophones that were about 2,600 and 6,000 meters away were established. This position was sometimes compromised by high background sounds due to strong tidal currents.*

The monitoring for the second season (i.e., 2021) of the PCT measured and recorded sounds with the following objectives:

- A sample size of two 144-inch piles was measured. The full duration of the impact driving was measured for both piles. Vibratory driving of the very short-duration pile stabbing events was measured; however, there were upset conditions for the first pile. The vibratory driver did not attach properly to the first pile, causing much higher noise levels, and the attempt to use the vibratory hammer on this pile was discontinued. The measured vibratory driving event of the second pile was successful and lasted a short duration of less than 2 minutes, since that was all the time needed by the Contractor to achieve penetration sufficient to be able to switch to the impact hammer.
- Measurements were made for approximately fourteen 36-inch-diameter template piles. Measurements were typically made at approximately 10 and 30 meters, with additional measurements made at farther distances out to 6,000 meters. However, sounds from vibratory driving at distances greater than the 600- to 800-meter locations were difficult to discern from ambient conditions due to noise generated by strong tidal currents.

1.4 Bubble Curtain

Sounds from pile driving was reduced using an air bubble curtain system. An unconfined air bubble curtain noise attenuation system (bubble curtain) was used during installation of piles to reduce underwater sound pressure levels. In a bubble curtain, a series of compressors provides a continuous supply of compressed air, which is distributed among the series of vertically distributed bubble rings made from pipes that surround the pile. Air is released through small holes in the bubble rings to create a curtain of air bubbles surrounding the pile. As the bubbles rise to the surface and expand, currents move the curtain horizontally. Bubbles released from the above layers of rings provide a continuous curtain around the pile throughout the entire water column with a range of bubble sizes at every depth to attenuate the sound. The lowest layer of perforated aeration pipe is designed to ensure contact with the substrate without burial and accommodate sloped conditions.

The bubble curtain system was designed to meet the general specifications below, as described in the PCT Incidental Harassment Authorization (IHA) application:

- A bubble curtain is composed of an air compressor(s), supply lines to deliver the air, distribution manifolds or headers, perforated aeration pipes, and a frame. The frame facilitates transport and placement of the system, keeps the aeration pipes stable, and provides ballast to counteract the buoyancy of the aeration pipes in operation.
- The aeration pipe system consisted of multiple layers of perforated pipe rings, stacked vertically in accordance with the following:

Water Depth (m)	**No. of Layers**
0 to less than 5	2
5 to less than 10	4
10 to less than 15	7
15 to less than 20	10
20 to less than 25	13

Note: m = meters.

- The pipes in all layers were arranged in a geometric pattern that allowed for the pile being installed to be completely enclosed by bubbles for the full depth of the water column, and with a radial dimension such that the rings are 1 to 2 feet (0.30 to 0.61 meters) from the outside surface of the pile.
- The design of the system ensured that the system extended from the sea floor to the water surface during maximum water-current conditions and accommodate tidal changes.
- Air holes were 1/16 inch (1.6 millimeters) in diameter and spaced approximately 3/4 inch (20 millimeters) apart. Air holes with this size and spacing were placed in four adjacent rows along the pipe to provide uniform bubble flux.
- The unconfined system provided a bubble flux of 105 cubic feet (3.0 cubic meters [m^3]) per minute per linear meter of pipe in each layer (32.91 cubic feet [ft^3] per minute per linear foot of pipe in each layer). The volume of air per layer (Vt) is the product of the bubble flux and the circumference of the ring: Vt = 3.0 m^3 /minute/meter * circumference of the aeration ring in meters or Vt = 32.91 ft^3 /minute/foot * circumference of the aeration ring in feet.
- Meters to monitor proper operation were provided as follows:
  - Pressure meters were installed at all inlets to aeration pipelines and at points of lowest pressure in each branch of the aeration pipeline.
  - Flow meters were installed in the main line at each compressor and at each branch of the aeration pipelines at each inlet. In applications where the feed line from the compressor was continuous from the compressor to the aeration pipe inlet, the flow meter at the compressor was eliminated.
  - Flow meters were installed according to the manufacture's recommendation based on either laminar flow or non-laminar flow, whichever applied.
- Gauges were installed above the water line and were photo-documented by the Contractor. The Contractor took pictures of the gauges each time the Contractor started driving a pile and sent them to POA's inspector.

Strong currents were encountered intermittently when deploying the bubble curtain in Knik Arm. As a result, the majority of pile driving was conducted around low tide, which served to (1) minimize sound propagation due to the lower water depths; (2) maintain a more continuous vertical bubble curtain surrounding the pile; and (3) simplify deployment and retrieval of the bubble curtain system (i.e., fewer vertically stacked rings required).

1.5 Underwater Sound Descriptors

The acoustic monitoring program reports data in several required formats, depending on the type of pile driving and the type of acoustic measurement. Impact pile driving produces pulse-type sounds, while vibratory pile installation produces a more continuous type of sound.

To compare with appropriate marine mammal and fish sound criteria, the sound pressure signals were reduced and analyzed to obtain maximum peak pressure level (peak), cumulative sound exposure level (SEL_{cum}), and RMS levels. The pressure versus time signals from all monitoring locations were processed using the same algorithms to calculate the required metrics. Peak pressure level is defined as:

$$L_{pk} = 20\ Log_{10}\ \left(P_{pk}/P_{ref}\right) \qquad (1)$$

where L_{pk} is the peak level in dB, and P_{ref} is the reference pressure of 1 µPa. SEL_{cum} is given by:

$$SEL_{cum} = 10\ Log_{10}\left(\int_0^T \frac{P^2(t)\ dt}{P_{ref}^2}\right) \qquad (2)$$

where T is the duration of the entire pile driving event, $P^2(t)$ is the instantaneous pressure squared, and P^2_{ref} is the reference pressure of 1 µPa. To numerically calculate SEL_{cum}, the following discrete summation is used:

$$SEL_{cum} = 10Log_{10}\left(\sum_{i=0}^{T} \frac{p_i^2}{p_{ref}^2} \Delta t_i\right) \qquad (3)$$

where Δt_i is the time resolution of the pressure versus time signal, p_i^2 is the pressure squared in a specific increment of time, and t is the total duration of the pile driving event. The RMS level is given by:

$$p_{RMS} = \sqrt{\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} p^2(t)dt} \qquad (4)$$

$$L_{RMS} = 20Log_{10}\left({}^{p_{RMS}}/_{p_{ref}}\right) \qquad (5)$$

where T_1 is the time at the beginning of the pile driving event, and T_2 is the time at the end. Numerically, the RMS calculation is given by:

$$L_{RMS} = 20Log_{10}\left\{\sqrt{\frac{1}{T_2-T_1}\sum_{T_1}^{T_2} p_i^2 \Delta t_i} \Big/ p_{ref}\right\} \qquad (6)$$

The RMS SPL is averaged over a defined time period in a stated frequency range or band. The appropriate time period to average for the RMS computation varies by the type of sound (e.g., pulsed or continuous). For vibratory pile driving, the RMS SPL was measured directly in 1-second intervals for the entire event. For impact pile driving, the RMS SPL was computed for each pile strike by averaging the squared pressures over the amount of time required to achieve 90 percent of the total sound energy. The average sound level during the measurement period is also computed to be the equivalent average sound pressure level (L_{eq}).

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2 Monitoring Methods and Equipment

Two pile installation operations occurred in May and June 2021, and both occurred from barges. One operation was to install (and eventually remove) the temporary 36-inch-diameter template piles, and the other operation installed the 144-inch-diameter mooring and breasting dolphin piles. Sequencing was arranged so that only one vibratory hammer was active at a time, in compliance with permit requirements. Hydroacoustic monitoring was conducted for both operations.

2.1 Monitoring Locations and Setup

Originally, three primary measurement locations were planned for this project: (1) 10 to 20 meters from the pile; (2) a mooring position about 1 km from the pile; and (3) a second mooring position about 3 km from the pile. Supplemental positions were added, and other positions were modified in the field as conditions warranted.

The POA proactively conducted some hydroacoustic monitoring when vibratory installation of 36-inch-diameter piles occurred prior to the planned sound source verification (SSV) in the fall of 2020. The purpose was to obtain acoustic data to ensure that sound levels associated with the improved confined bubble curtain were consistent with predicted levels. These measurements were limited to positions within the work area of about 10 and 30 meters. The SSV included attempts to measure at approximately 600 to 800 meters, about 2.6 km, and a few times at about 6 km. The original plan was to measure the sounds from installing 4 piles, but this was expanded to 14 piles. However, measurements in the far-field[3] were difficult to obtain because of the strong tidal currents and limited availability of a vessel.

The temporary 36-inch piles were typically driven during outgoing (ebb) tides when strong tidal currents were present. These strong tidal currents impeded efforts in two ways: (1) the initial moorings could not hold in these strong currents, and additional reenforcing of the anchors was required; and (2) there was considerable noise most of the time when currents were strong. It should be noted that these piles were driven during a period of large tidal changes on the order of 10 meters that caused strong currents. Measurements were attempted at distances of 10 meters to 6 km. For positions within the work area, water depths were intended to be at mid-depth level; however, water depths changed quickly during much of the driving. At the POA, depths ranged from approximately 10 to 20 meters; near the deepest portion of Knik Arm, at 800 meters, water depths were approximately 20 to 30 meters; at about 2,800 meters, in the western portion of Knik Arm, depths ranged from 8 to 20 meters; and in the southern portion of the Arm, at about 6,000 meters, depths were between 5 and 15 meters. Bottom-mounted hydrophones were at 1 to 1.5 meters above the seafloor, as current speeds seemed slower at this depth and therefore this was the only depth that could be measured for unattended systems.

Measurements for the 144-inch-diameter monopiles were collected at positions of 19 meters to about 6 km. Measurements were not possible at closer positions because of the barge placement and bubble flux area, which extends about 10 to 15 meters from the pile. For Pile MD-5, the closest possible position was at the South Floating Dock, (SFD), 31 meters from the pile. The crane extends about 20 to 30 meters from the construction barge; therefore, the construction barge was usually 20 meters or farther from the pile.

[3] The far-field points consist of one measurement at 72 meters from the pile, and the rest at more than 500 meters from the pile.

Intermediate positions were added to the monitoring design to include measurements at about 30 and 100 meters. Distant positions were fixed at about 0.6, 2.6, and 6 km.

Figure 2-1. Project area showing far-field monitoring positions

Close-in hydrophones were deployed from the construction barge for 36-inch temporary template piles, the SFD for the 144-inch monopiles, the new PCT platform for both piles, and the existing POL 1 (Petroleum, Oil, Lubricants) dock for the 144-inch MD-6 pile.

The first mooring position, which was targeted for deployment at 1 km, was typically located approximately 600 to 800 meters from the piles. Closer positioning was necessary to avoid other vessels and the strongest currents. The targeted mooring position of 3 km was located across Knik Arm typically at about 2.6 km. This mooring position was just west of strong currents where a minimum water depth of 10 meters was measured. Due to strong currents and shifting bottom sediments, securing this hydrophone was problematic. The 6-km position was placed to the southwest where the water depth was about 8 to 18 meters, depending on tide, and avoided the strongest currents and wave action. Very strong tidal currents were an issue in obtaining all acoustic measurements. No mooring-based hydrophones could be placed in the construction zone due to obstructions, strong currents, and overhead construction hazards. The hydrophone equipment was lost or had to be retrieved multiple times.

2.2 Monitoring Equipment

The measurement equipment and specifications used for this project are shown in Table 2-1.

The close-in and SFD positions consisted of Reson Model TC-4033 hydrophones with PCB in-line charge amplifiers (Model 422E13) that were fed into Larson Davis Model 831 or 831C Precision Sound Level Meters (LDL 831 or 831C SLMs). Figure 22 shows an example of this setup. The dipping method was used primarily for deployment of these hydrophones (i.e., the hydrophones were deployed from a structure and weighted).

These were supplemented with autonomous hydrophone units, which consisted of Reson Model TC-4013 hydrophones with PCB 422E04 in-line charge converters and PCB 482A22 signal conditioners. These signals from the autonomous units were recorded using solid state Roland R-05 or R-07 audio recorders, which were run through the LDL 831 or 831C SLMs during post-processing. Figure 2-3 shows the autonomous units. These units were typically deployed at close-in positions either as primary hydrophones or as backup systems.

The mooring positions were unmanned monitoring positions that were deployed well before pile driving activities began and retrieved at the end of each day. These positions consisted of the Loggerhead Snap units, which included High Tech, Inc., Model HTI-96-MIN hydrophone with a Seacon MCIL3M and MCDLSF connector. The signals from these hydrophones were recorded directly to a memory card embedded in a circuit board housed in the Loggerhead unit. Figure 2-4 shows the Loggerhead units.

For both the autonomous and Loggerhead systems, the equipment was bottom-anchored, allowing the hydrophone systems to float up from the bottom. Figure 2-5 shows both deployment methods used for this project.

Tidal changes in Knik Arm are large and cause strong tidal currents. These currents are commonly associated with large swirling eddies that cause sudden changes in water flow over short time periods. In an effort to reduce the effects of flow noise, shields were placed over the hydrophones (see Figure 2-6), which reduces the effects of water directly impacting the hydrophone.

Recordings were analyzed in two ways. The recorded vibratory signals were measured using the LDL 831 that provided 1-second L_{eq} levels for each 1/3-octave band level. For impact pile driving, the recordings were measured with the LDL 831 to measure 1-second L_{eq} levels for each 1/3-octave band level and then run through a National Instruments Labview program to obtain pulse levels that included peak, SEL, RMS, and the duration of the 90 percent RMS pulse. While the LDL 831 measures sounds between 1/3-octave bands of 6.3 to 20,000 Hertz (Hz), the overall L_{eq} sound levels reported were summed from 20 to 20,000 Hz to avoid contamination from flow effects at very low frequencies.

Table 2-1. Acoustic monitoring equipment

Item	Specifications	Quantity	Usage
Hydrophone	Receiving Sensitivity – Reson 4013 at -211 dB ± 3 dB re 1 V/µPa, Reson 4033 -203 dB + 2 dB re 1 V/µPa, and HTI96-min -180 dBV/µPa HTI96-min -210 dBV/µPa	5 + 3 backup	Capture underwater sound pressures and convert to voltages that can be recorded/analyzed by other equipment. Note various sensitivities required to range and different types of sound.
Signal Conditioning Amplifier	Amplifier Gain - 0.1 mV/pC to 10 V/pC Transducer Sensitivity Range- 10-12 to 103 C/MU	4	Adjust signals from hydrophone to levels compatible with recording equipment. Required for recording systems that do not use LDL 831C.
Roland R-05 and R-07, SNAP Audio Recorders	Sampling Rate - 48 kHz or greater	4 + 2 backup systems	Record pile driving sound levels at hydrophone position.
GRAS 42AA and 42 AC Pistonphone Calibrator and Coupler	Accuracy - IEC 942 (1988) Class 1	2	Perform calibration check of hydrophone in the field.
Larson Davis 831 and 831C Model Sound Level Meter	Sampling Rate - 51.6 kHz	4	Measure sound pressure levels and record sound levels.
Flow Shield	Reduce flow rate against hydrophone surface	6	Reduce flow noise contamination, where appropriate.
Laptop Computer with Pulse Analysis Software	Compatible with digital signal analyzer	2	Analyze pile driving recordings to compute pulse levels for IHA Level B calculations.

Note: C/MU = coulombs/mechanical unit; dB = decibels; dBV/µPa = decibel volts per microPascal; IHA = Incidental Harassment Authorization; kHz = kilohertz; mV/pC = microvolts per picocoulombs; V = volts; V/pC = volts per picocoulombs; V/µPa = volts per microPascal.

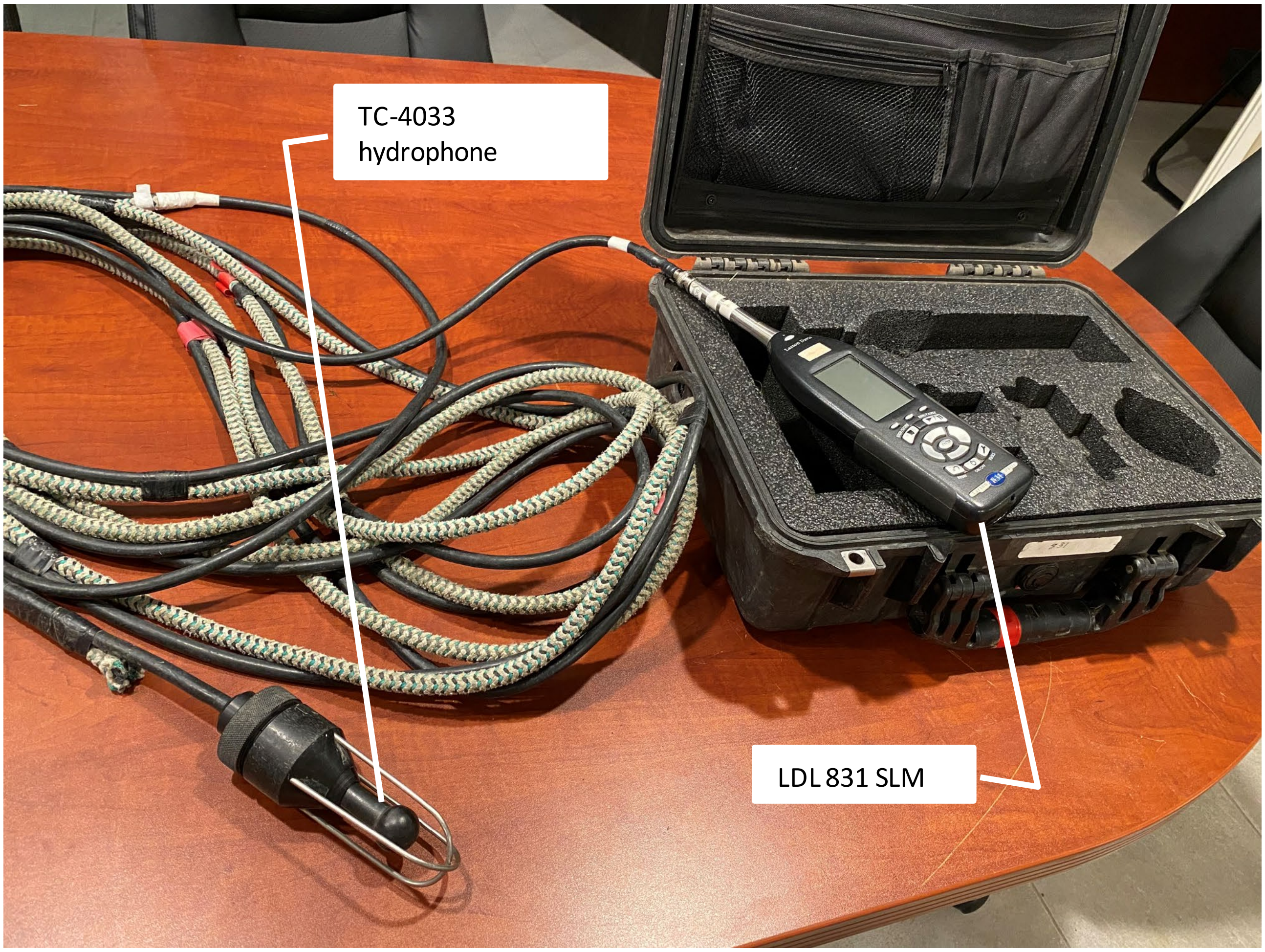

Figure 2-2. Typical hydrophone system used at the close-in, SFD, and drifting vessel positions

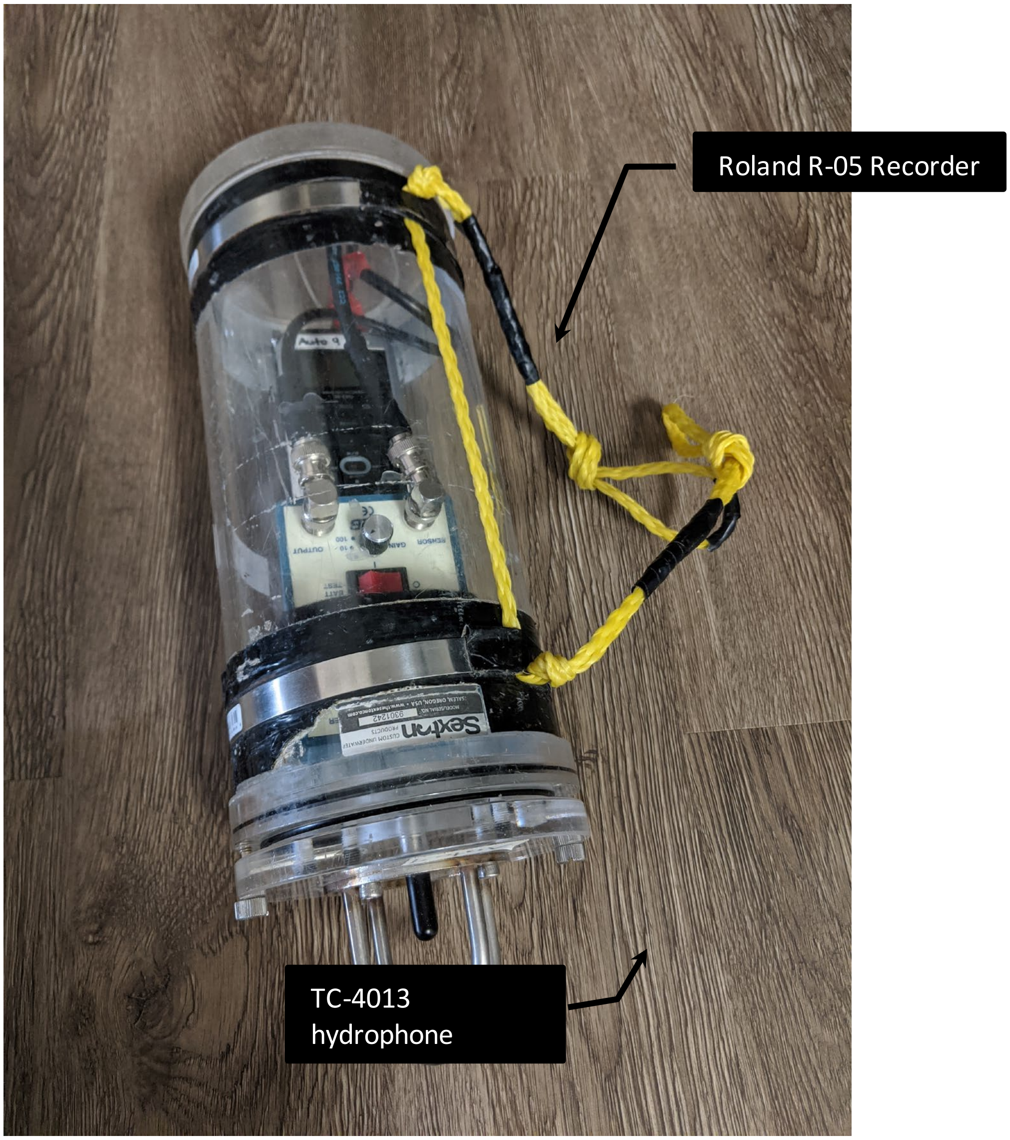

Figure 2-3. Autonomous units used at the close-in, SFD, and mooring positions

Figure 2-4. Loggerhead Snap units used at the mooring positions

Dipping hydrophone system

Mooring in current for hydrophone placed at approximately 800 meters from pile driving

Figure 2-5. Examples of hydrophone deployments

Figure 2-6. Example of hydrophone flow shield

2.2.1 Underwater System Acoustic Calibration

The measurement systems were calibrated prior to and following use in the field with a G.R.A.S. Type 42AC Pistonphone and hydrophone coupler. A pistonphone is an acoustical calibrator used to generate a precise sound pressure for the calibration of instrumentation microphones. The pistonphone, when used with the hydrophone coupler, produces a continuous 136.4 dB re 1 µPa tone for the TC-4033 hydrophones at 250 Hz. For the TC-4013 hydrophones, the calibration tone is 145.3, 165.4, or 185.3 dB depending on the setting of the power supply. The Loggerhead Snap units generated a tone of 143.4 dB. The tone measured by the SLM was recorded at the beginning of the recordings. The system calibration status was checked at the beginning of each measurement day by measuring the calibration tone. The same process was completed following each measurement day. The pistonphones were certified at an independent facility.

All field notes were recorded in water-resistant field notebooks. Notebook entries included calibration notes, measurement positions (i.e., distance from source, depth of sensor), measurement conditions (e.g., currents, sea conditions), system gain settings, and the equipment used to make each measurement. Notebook entries were copied after each measurement day and filed for safekeeping. Digital recordings were also copied and stored for subsequent analysis, if needed.

2.2.2 Hydrophone Frequency Response Discussion

Reson TC-4013 and TC-4033 hydrophones, along with HTI-96 MIN hydrophones, were deployed. The Reson TC-4013 hydrophones were used in the close-in autonomous units. The Reson 4033 hydrophones were used in the dipping hydrophone systems. The HTI-96 MIN hydrophones were equipped in the Loggerhead Snap autonomous recording system. The frequency responses of these hydrophones are shown on Figure 2-7 through Figure 2-9. The TC-4033 hydrophone is quoted as having a usable frequency from 1 Hz to 140 kilohertz (kHz) and the TC-4013 from 1 Hz to 170 kHz. HTI-96-MIN is from 1 Hz to about 30 kHz. Because of the nature of the piezoelectric sensor elements of these transducers, the frequency response in the range from 1 Hz to 5 kHz is flat. The measured frequency responses extend down in frequency to 5 kHz for the Reson TC-4013 and TC-4033 hydrophones and 1 kHz for the HTI-96-MIN. Because of the very long wavelengths in water below 1 kHz, frequency response cannot be measured in calibration facilities. For this reason, it is not feasible to apply frequency corrections to the measured data in the lower frequency ranges important for marine mammals.

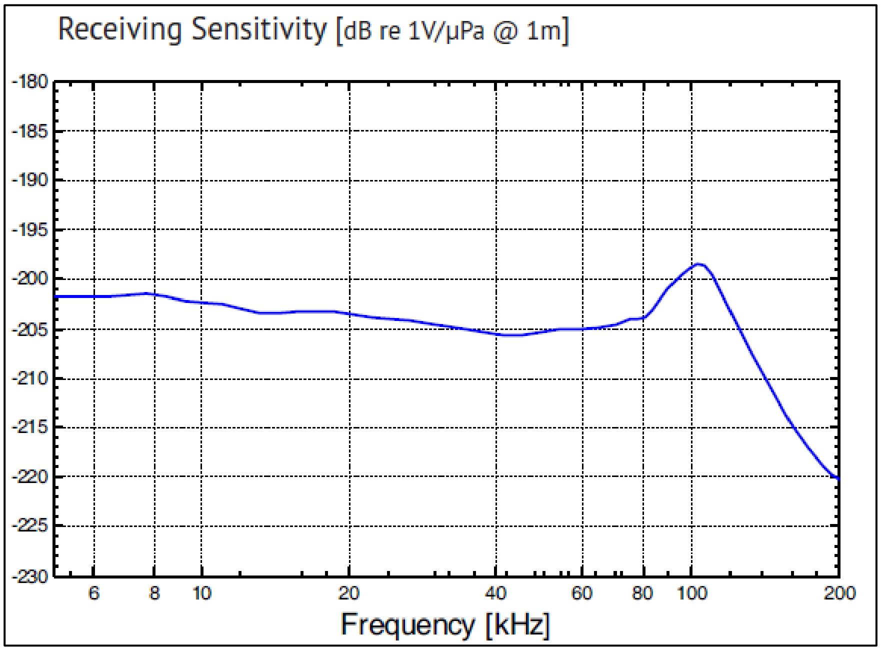

Figure 2-7. Frequency response of the TC-4033 hydrophones

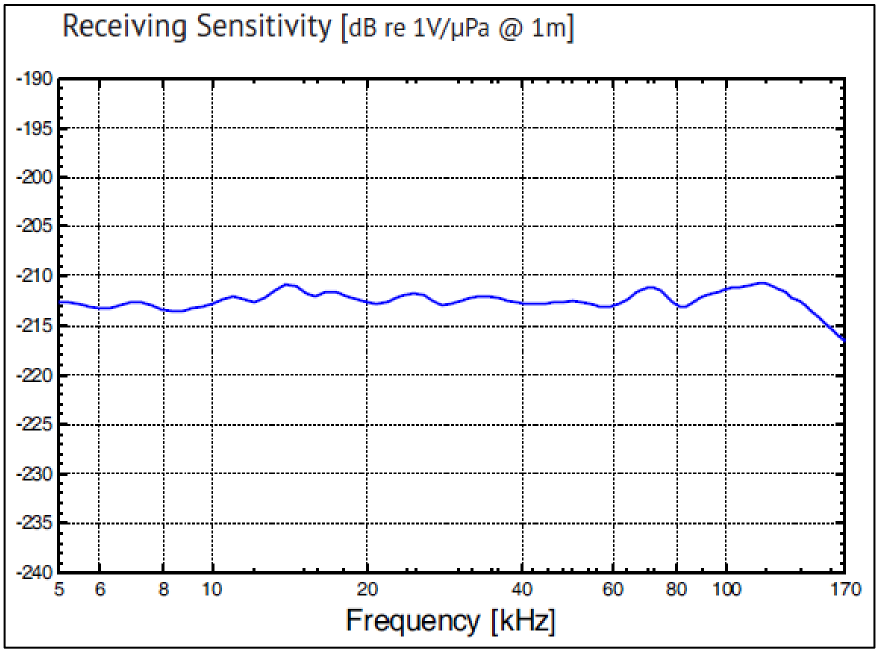

Figure 2-8. Frequency response of the TC-4013 hydrophones

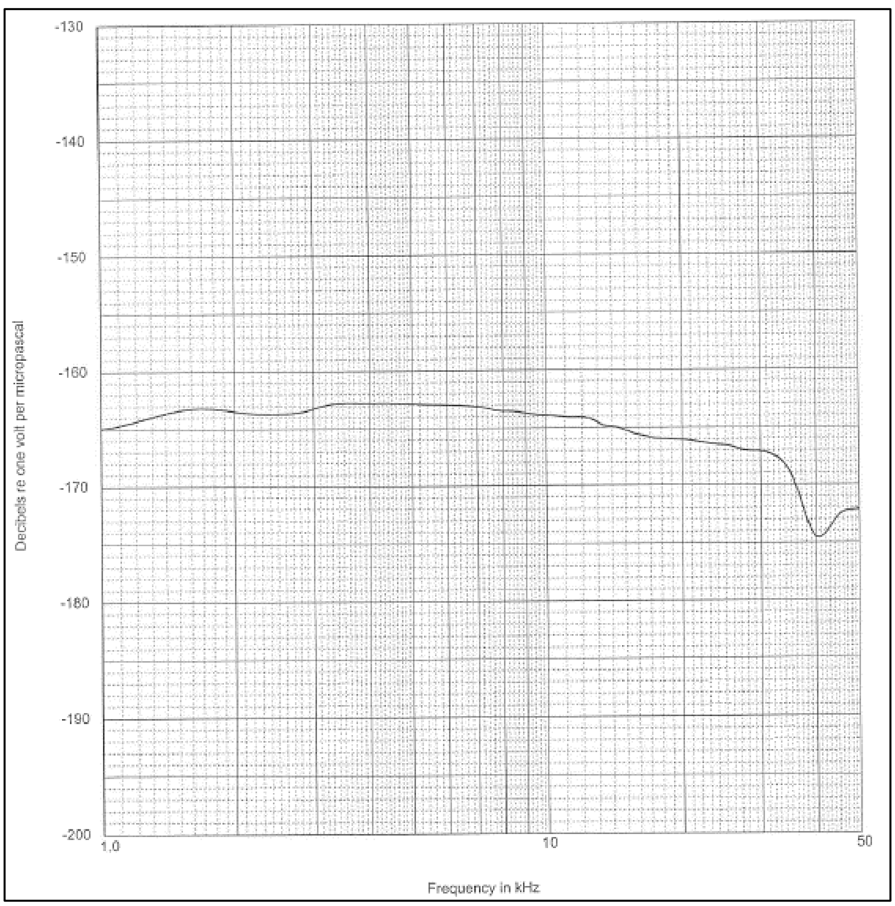

Figure 2-9. Frequency response of the HTI-96-MIN hydrophones

2.3 Equipment Deployment Challenges

The marine conditions in Knik Arm were challenging for deployment of acoustical equipment. The two primary challenges were strong tidal currents and significant water depth changes. Strong currents required careful placement of hydrophone systems.

For nearshore conditions, currents[4] were generally weaker, and hydrophones could be placed from nearby structures or the barge. However, current speeds could be erratic when large tidal circulations or eddies were present that increased or decreased current speeds unexpectedly. Various deployment methods had to be used in these cases. Background noise could be elevated, especially at lower frequencies.

At the distant mooring positions, strong currents that also caused shifting bottom conditions affected measurement positions. Positions at 1 km from pile driving operations were evaluated in 2020 prior to the measurement program to ensure that moorings would hold and quality sound recordings could be obtained. Eventually, a position that was about 660 to 890 meters was established. However, this position was exposed to strong currents at times. The hydrophone was positioned at about 1 to 1.5 meters above the bottom to avoid higher current speeds. The mooring at this position failed several times due to strong current and had to be retrieved. Several times, the hydrophone system was detached by strong currents. The intended 3-km position was established at about 2.6 km where current and bottom conditions were less turbulent. This system was exposed to strong currents also, and the mooring failed during two of the deployments. A 6-km mooring position was established for measurements during the driving of the 144-inch monopiles. This system was deployed for some 36-inch temporary piles, as well; however, those sounds were too weak and could not be measured above background at that position.

For all positions, background sound, especially at very low frequencies, affected measurements. This likely biased some of the sounds generated by vibratory driving during the quieter portions of those driving events. During louder events, current effects had little or no effect on overall sound levels.

Water depth changed substantially over the course of a tidal change. During the course of a day, water depth changed by about 10 meters. Hydrophones deployed from structures were adjusted in an attempt to maintain an approximate mid-depth position. Many of the measurements were based on deployment of moored systems that maintained a depth of 1 to 1.5 meters above bottom. This was found to be the most successful method to obtain data that were least contaminated by flow effects.

2.4 Data Analysis

For the systems with the LDL 831, the data were collected in real time. Data were collected every second from just before each pile driving activity until just after. The duration varied, but typically recordings began several minutes before the pile driving event began and ended several minutes after the pile driving event ended. One-third-octave band spectra, RMS levels, and peak levels were measured using SLMs for vibratory pile driving. For impact driving, the spectra, single-strike SEL (as 1-second L_{eq}), RMS, and peak levels were

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[4] Current measurements were not made as part of the hydroacoustic measurement effort. There were current measurements made on May 27, 2021, near the Port facilities that indicated surface speeds of up to 3.5 knots. However, speeds in excess of 6 knots are predicted outside the Port. Currents experienced by the hydroacoustic monitoring crew were typically greater than 3 knots, and retrieval of hydrophones was quite often difficult. While current measurements were not conducted, GPS positioning systems indicated random observation of speeds of 7 knots.

collected. RMS levels for vibratory and single-strike SEL (for impact) were computed over the 1/3-octave band frequency range of 20 to 20,000 Hz.

At each monitoring position, sounds were recorded. Calibration tones for specific amplitudes and frequency were also recorded to allow measurements of the recorded sounds. The recorded sounds were then analyzed using the LDL 831. Impact pile driving sounds were analyzed using the LDL 831 to measure peak and SEL (as 1-second L_{eq}). To obtain the pulse RMS levels and the time durations where 90 percent of the energy of the pulse occurs, a separate pulse analysis was conducted by running the recordings into National Instruments LabVIEW program, which is designed to capture the peak sound pressure level, the 90 percent RMS level, the single-strike SEL of the pulse, cumulative SEL, and 90 percent pulse duration for each pile strike.

3 Description of Measurements

3.1 Marine Mammal Weighting Curves and Criteria

Under the MMPA, NMFS has defined levels of harassment for marine mammals. Level A harassment is defined as "Any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or marine mammal stock in the wild." Level B harassment is defined as "Any act of pursuit, torment, or annoyance which has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including but not limited to migration, breathing, nursing, breeding, feeding or sheltering." Current NMFS guidance (NMFS 2018) categorizes marine mammals into five functional hearing groups, and the sound thresholds for Level A and Level B harassment for these groups are shown in Table 3-1.

Table 3-1. Underwater acoustic thresholds used for marine mammals

<table>
<tr><th rowspan="3">Species Hearing Group</th><th colspan="2">Non-Impulse Sound (Vibratory Pile Driving)</th><th colspan="3">Impulse Sound (Impact Pile Driving)</th></tr>
<tr><th rowspan="2">Level A Weighted (dB SEL_{cum})</th><th rowspan="2">Unweighted Level B (dB RMS)</th><th colspan="2">Level A Dual Criteria</th><th rowspan="2">Unweighted Level B (dB RMS)</th></tr>
<tr><th>(dB Peak)</th><th>Weighted (dB SEL_{cum})</th></tr>
<tr><td>Low-Frequency Cetaceans (e.g., humpback whale)</td><td>199</td><td rowspan="5">120 or background</td><td>219</td><td>183</td><td rowspan="5">160</td></tr>
<tr><td>Mid-Frequency Cetaceans (e.g., beluga whale)</td><td>198</td><td>230</td><td>185</td></tr>
<tr><td>High-Frequency Cetaceans (e.g., harbor porpoise)</td><td>173</td><td>202</td><td>155</td></tr>
<tr><td>Phocids (e.g., harbor seal)</td><td>201</td><td>218</td><td>185</td></tr>
<tr><td>Otariids (e.g., Steller sea lion)</td><td>219</td><td>232</td><td>203</td></tr>
</table>

Note: All decibels (dB) are referenced to 1 microPascal (re: 1 µPa). Level A SEL_{cum} levels are weighted using auditory weighting filter shapes shown on Figure 3-1. RMS = root mean square; SEL_{cum} = cumulative sound exposure level.

To apply the Level A criteria, the auditory weighting curves shown on Figure 3-1 were applied to the unweighted median spectra at each monitoring location for each pile driving event by species category. This was accomplished by subtracting the value of the weighting curve at each 1/3-octave band center frequency from the corresponding 1/3-octave measured spectrum. The 1/3-octave band levels were summed on an energy (logarithmic) basis to produce the overall weighted level per second or per pile strike. The number of seconds or pile strikes were combined to compute the overall accumulated SEL levels that were compared to the thresholds shown in Table 3-1.

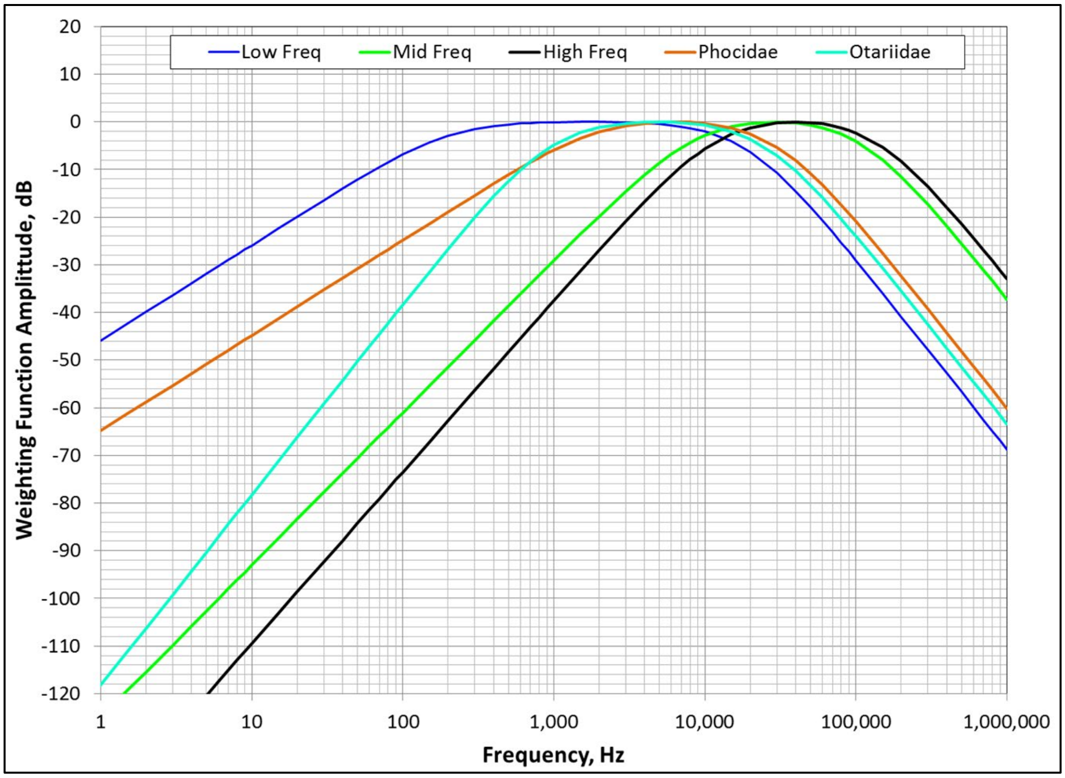

Figure 3-1. Marine mammal auditory weighting filter shapes from the 2018 NMFS Technical Guidance

3.2 Pile Driving and Acoustic Monitoring Events

3.2.1 Vibratory Pile Driving Events

Vibratory monitoring for 36-inch-diameter piles occurred May 17–27, 2021, and attempts to measure vibratory driving of 144-inch piles occurred on May 24, 26, and 29, 2021. No driving was conducted on May 24 because the pile could not be properly set up due to site conditions. The vibratory driving on May 26 was terminated due to complications attaching the driver to the pile, although driving was briefly attempted. Vibratory installation of a 144-inch pile occurred on May 29. Monitoring for vibratory pile driving was completed for fourteen 36-inch piles and two 144-inch piles. An unconfined air bubble curtain was used during all driving events.

3.2.2 Impact Pile Driving Events

Impact pile driving monitoring was conducted on May 27 and 29, 2021, for two 144-inch-diameter monopiles.

3.2.3 Ambient Noise Environment

Ambient levels were most recently measured near the POA in 2016 at two locations, one within the POA and one about 1 km offshore of the POA, during a 3-day break in pile installation during the POA Test Pile Program. The median values of the background sound pressure levels from continuous 60-second sample averages were 117.0 dB at the nearshore location within the POA and 122.2 dB at the offshore location (POA 2016). During the measurements, some typical sound signals were noted, such as noise from current flow and the passage of vessels. Throughout the data set, the offshore levels were consistently higher than those closer to the POA by 3 to 5 dB. The offshore measurements of sound over time showed a distinct pattern of increased sound levels in the 10- to 100-Hz range that were associated with tidal cycles. Much of the increase occurred in the 10- to 20-Hz range. The ambient noise level of 122.2 dB, measured offshore, was used for the PCT Project to assess the extent of Level B sounds from continuous sources. The extent of Level B areas from the POA activity occurs in the offshore waters.

Typical anthropogenic noise sources encountered during this monitoring event included sounds from the dredging operation, tugs that support freight or petroleum barges, and ships and shipping (see Figure 3-2).

(a) Dredge disposal offshore of PCT construction area

(b) TOTE ship with support offshore of PCT construction area

Figure 3-2. Examples of anthropogenic sound sources in Knik Arm

For this study, background levels were analyzed prior to and following pile driving events at each of the measurement positions. Typically, measurements began several minutes before pile driving and continued several minutes after pile driving. Background levels ranged from 120 to 135 dB over the frequency range of 20 to 20,000 Hz at monitoring locations within approximately 200 meters of the pile driving activities.

At distances beyond 500 meters, background levels were about 115 to 140 dB. Depending on environmental conditions, such as water currents, background levels were at times higher than these typical levels. Measured ambient levels prior to or after a measured event are shown in each of the time histories provided in Chapter 5 of this report. Figure 3-3 provides an example of quieter sounds that were measured at each monitoring position on May 26, 2021.

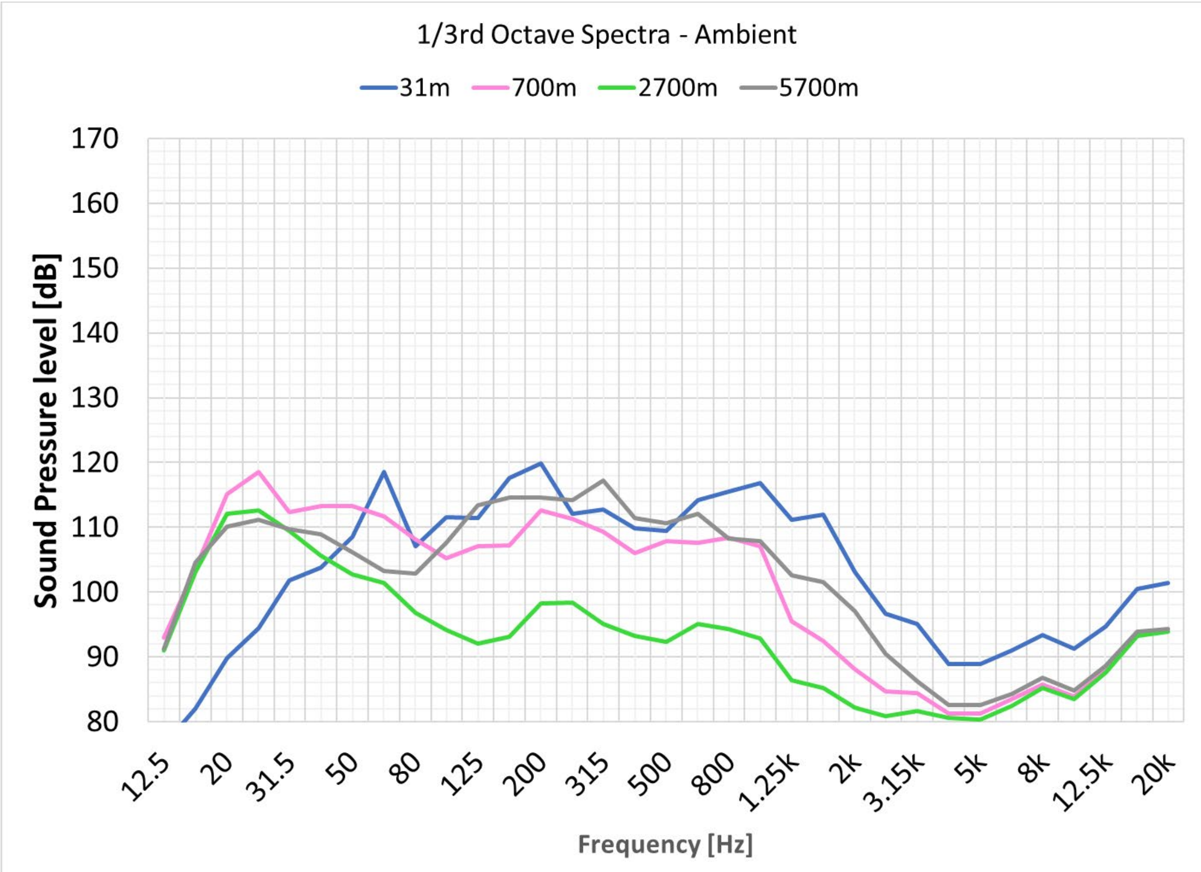

Figure 3-3. Sample of 1/3-octave band spectra for ambient sound pressure levels at each monitoring location (data from May 26, 2021, measurements)

3.2.4 Effect of Ambient Levels and Background Sounds

Some measurements conducted at far-field conditions were affected by background or ambient sounds. The ambient sound level of 122.2 dB is the threshold for Level B harassment zones identified in the IHA. As described above, this was the ambient sound level measured offshore in 2016. The ambient sound level is the median level measured over a 72-hour period. Background noise was typically the result of strong current flow affecting the hydrophone and signal line. This was evident by examining the frequency spectra that indicated elevated sounds above 120 dB in the frequencies below 100 Hz. In some cases, vessel traffic or other unidentified sounds may have temporarily affected measurements. Examples include maneuvering of the dredge tug. Note that the Knik Arm is not a busy seaway and vessel activity is not common.

Overall measured sound levels of piling activity that are within 10 dB of the ambient sound level would be affected by background sound. Vibratory sounds measured at the very distant positions were typically within 2 to 15 dB of ambient sound levels. The contribution of background sounds, mostly flow noise, elevated distant measured vibratory sounds by up to 2 dB. Measured vibratory sound levels at these positions were adjusted by subtracting the measured background sound level taken prior to or just after vibratory pile installation. This was conducted by using a segment of the recording that did not have any pile driving, essentially measuring the background level, which was then logarithmically subtracted[5] from the measured piling activity. A 2-dB adjustment was the maximum adjustment applied. The impact pile driving sounds were not affected by ambient sound conditions, as they were more than 10 dB above ambient or background levels.

[5] "Logarithmically subtracted" means 10*log10[(10^(Measured level/10) - 10^(Background level/10)].

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4 Measurement Activities and Observations

This chapter discusses the daily activities and observations on each day of monitoring. Data collected for each of these days are summarized in Chapter 5.

4.1 May 17, 2021, Pile Driving Activities

Hydroacoustic measurements were made during the vibratory installation of the 36-inch temporary template piles MD5-A and MD5-B. The vibratory hammer used for both installations was an APE 300-6. The air bubble curtain was operational during the installation.

4.1.1 Vibratory Pile Driving Activities

Driving of pile MD5-A started at 2:31 p.m. and concluded at 2:38 p.m. The actual driving time was 5.0 minutes. Water depth at the pile was about 14 meters. There were two measurement monitoring positions: at 11 meters from the pile, deployed from the construction barge; and at 31 meters from the pile, deployed from the nearby SFD. The water depth at the near location (11 meters) was 14 meters and at the farther location (31 meters) was 10 meters. The hydrophones were deployed at mid-depth, with backup systems at 1 to 1.5 meters above the bottom.

Pile MD5-B was driven from 3:29 p.m. to 3:37 p.m., with a total drive time of 5.9 minutes. Water depth at the pile was 13 meters. Measurement positions were made at 12 meters in 13-meter-deep water and at 30 meters in 9-meter-deep water. Both hydrophones were positioned about mid-depth.

4.1.2 Impact Pile Driving Activities

No impact driving was conducted this day.

4.2 May 18, 2021, Pile Driving Activities

Hydroacoustic measurements were made during the vibratory installation of the 36-inch temporary template piles MD5-D and MD5-C. The vibratory hammer used for both installations was an APE 300-6. The air bubble curtain was operational during the installation.

4.2.1 Vibratory Pile Driving Activities

Driving of pile MD5-D started at 2:53 p.m. and concluded at 3:00 p.m. The actual driving time was 5.8 minutes. Water depth at the pile was about 13 to 15 meters. There were two measurement positions: at 10 meters from the pile and deployed from construction barge; and at 30 meters from the pile and deployed from the SFD. The water depth at the near location (10 meters) was 15 meters and at the farther location (30 meters) was 11 meters. Hydrophones were positioned about mid-depth.

Pile MD5-C was driven from 3:56 p.m. to 4:06 p.m. along with vibratory removal/driving to obtain the correct tip elevation from 4:06 p.m. to 4:07 p.m. The total drive time was 9.2 minutes. Water depth at the pile was 13 meters. Measurement positions were made at 19 meters in 13- to 15-meter-deep water and at 38 meters in 9- to 11-meter-deep water. Hydrophones were positioned near mid-depth.

4.2.2 Impact Pile Driving Activities

No impact driving was conducted this day.

4.3 May 19, 2021, Pile Driving Activities

Hydroacoustic measurements were made during the vibratory installation of the 36-inch temporary template piles MD6-A and MD6-B. The vibratory hammer used for both installations was an APE 300-6. The air bubble curtain was operational during the installation.

4.3.1 Vibratory Pile Driving Activities

Driving of pile MD6-A started at 11:24 a.m. and concluded at 11:32 a.m. The actual driving time was 6.1 minutes. Water depth at the pile was about 14 meters. There were two measurement positions: at 10 meters from the pile and deployed from the construction barge; and at 25 meters from the pile and deployed from the SFD. The water depth at the near location (10 meters) was 14 meters and at the farther location (25 meters) was 10 meters. Hydrophones were positioned at mid-depth.

Pile MD6-B was driven from 1:00 p.m. to 1:08 p.m., with a total drive time of 4.9 minutes. Water depth was 14 meters at the pile. Measurement positions were 5 meters above the bottom at the near location (10 meters) in 14-meter-deep water and at 3.5 meters above bottom at the farther location (29 meters) in 13-meter-deep water.

4.3.2 Impact Pile Driving Activities

No impact driving was conducted this day.

4.4 May 20, 2021, Pile Driving Activities

Hydroacoustic measurements were made during the vibratory installation of the 36-inch temporary template piles MD6-D and MD6-C. The vibratory hammer used for both installations was an APE 300-6. The air bubble curtain was operational during the installation.

4.4.1 Vibratory Pile Driving Activities

Driving of pile MD6-D started at 8:23 a.m. and concluded at 8:31 a.m. The actual driving time was 6.3 minutes. Water depth at the pile was about 10 meters. There were two measurement positions: at 10 meters from the pile and deployed from the construction barge; and at 30 meters from the pile and deployed from the SFD. The water depth at both the near position (10 meters) and at the farther location (30 meters) was 10 meters. Hydrophones were positioned at mid-depth.

Pile MD6-C was driven from 9:24 a.m. to 9:33 a.m., with a total drive time of 7.2 minutes. Water depth at the pile was 10 meters at about mean low level water. Measurements were conducted at three different positions during the vibratory driving: at 11 and 32 meters, where water depths were 10 meters; and at 2,640 meters, where water depth was at 11 meters. The hydrophone at the nearest location was positioned about 3 meters above the bottom, and the 32-meter hydrophone was positioned about 1.5 meters above the bottom. At the 2,640-meter location, the measuring hydrophone was attached to a mooring buoy deployed approximately 1.5 meters from the bottom and was retrieved at the end of pile driving.

4.4.2 Impact Pile Driving Activities

No impact driving was conducted this day.

4.5 May 25, 2021, Pile Driving Activities

Hydroacoustic measurements were made during the vibratory installation of the 36-inch temporary template piles MD3-D and MD3-C. The vibratory hammer used for both installations was an APE 300-6. The air bubble curtain was operational during the installation.

4.5.1 Vibratory Pile Driving Activities

Vibratory driving of pile MD3-D started from 7:43 a.m. to 7:52 a.m. and again from 8:59 a.m. to 9:00 a.m. The actual driving time was 7.6 minutes. Water depth at the pile was about 15 to 16 meters. There were three measurement positions: 29, 700, and 2,670 meters from the pile. The 10-meter measurement location was not feasible due to lack of access to the construction barge. The water depth at the pile and 29-meter monitoring location was 16 meters during the initial period of driving and reduced to 15 meters during the additional 1 meter of driving from 8:59 to 9:00. At the distant locations of 700 meters and beyond, the measuring hydrophone was attached to a mooring buoy and retrieved at the end of pile driving.

Pile MD3-C was driven from 8:39 a.m. to 8:54 a.m., with a total drive time of 9 minutes. Water depth at the pile was about 15 to 16 meters at high-level water. Measurements were conducted at three different positions during the vibratory driving: 29, 700, and 2,670 meters. The 10-meter measurement location was not feasible due to lack of access to the barge. The hydrophone at the nearest location was positioned about 4 meters above the bottom in a water depth of 15 to 16 meters. At the distant locations of 700 meters and beyond, the measuring hydrophone was attached to a mooring buoy and retrieved at the end of pile driving.

Measurements were conducted at around 6 km for both piles (MD3-D and MD3-C), but vibratory driving sounds could not be measured due to noise from the strong tidal currents. The vibratory pile driving could not be detected over background levels.

4.5.2 Impact Pile Driving Activities

No impact driving was conducted this day.

4.6 May 26, 2021, Pile Driving Activities

Hydroacoustic measurements were made during the vibratory installation of the 36-inch temporary template piles MD3-A and MD3-B, along with vibratory shaking of one 144-inch monopile (MD5). The APE 300-6 was used to drive the 36-inch-diameter piles (MD3-A and MD3-B), and the APE 600 Quad Beam vibratory driver was used in attempting to stab and begin installation of the 144-inch MD5 pile. The air bubble curtain was operational during the installations.

4.6.1 Vibratory Pile Driving Activities

Vibratory driving of pile MD3-A occurred from 8:44 a.m. to 8:55 a.m. and again from 9:57 a.m. to 9:58 a.m. The actual driving time was 9.1 minutes. Water depth at the pile reached 17 meters at high tide. There were three measurement positions: 11, 30, and 660 meters from the pile. A fourth location was deployed at approximately 2,700 meters, but the mooring for this system did not hold under the very strong currents. The water depth at the 11- and 30-meter locations was 17 meters. The hydrophone at the nearest location was positioned at mid-depth, approximately 8 meters deep. At the distant location of 660 meters, the measuring hydrophone was attached to a mooring buoy and retrieved at the end of pile driving.

Pile MD3-B was driven from 9:43 a.m. to 9:52 a.m., with a total drive time of 7.7 minutes. Water depth at the pile was about 15 meters at high level water. Measurements were conducted at two different positions during the vibratory driving: 11 and 660 meters. A third location was deployed at approximately 2,700 meters, but this system again failed under the strong currents. The seafloor bottom at that location is likely sandy and did not hold the mooring anchor well. The hydrophone at the nearest location was positioned mid-depth in water that was 15 meters deep. At the distant location of 660 meters, the measuring hydrophone was attached to a mooring buoy and retrieved at the end of pile driving. Measurements were conducted at around 6 km for both piles (MD3-A and MD3-B), but pile driving sounds were not measurable due to background noise. The strong currents generated noise where vibratory sounds were not audible.

Pile MD5 was attempted to be stabbed with a vibratory hammer. The driver could not be properly attached to the pile, so vibratory driving could not be accomplished. During attempts to connect the driver to the pile, the driver was activated, causing a loud “shaking” of the pile. This occurred several times in short bursts between 3:45 p.m. to 4:17 p.m., with a total shaking time of about 1 minute. The sound from this activity was measured at five different positions: 31 and 100 meters from the pile at 17-meter water depth; 700 meters at 30-meter water depth; 2,700 meters at 17-meter water depth; and 5,700 meters at 20-meter water depth. The water depth at the pile was about 10 meters.

4.6.2 Impact Pile Driving Activities

No impact driving was conducted this day.

4.7 May 27, 2021, Pile Driving Activities

Hydroacoustic measurements were made during the vibratory installation of the 36-inch temporary template piles MD2-C and MD2-D, along with impact installation of one 144-inch pile (MD5). The vibratory hammer used for piles MD2-C and MD2-D was an APE 300-6, while the impact hammer used for pile MD5 was an IHC S-800. The air bubble curtain was operational during all driving activities.

4.7.1 Vibratory Pile Driving Activities

Vibratory driving of pile MD2-C occurred from 9:24 a.m. to 9:28 a.m. and again from 10:11 a.m. to 10:12 a.m. The actual driving time was 4.6 minutes. Water depth at the pile was about 18 meters. There were three measurement positions: 72, 575, and 2,650 meters from the pile. The water depths at the locations were 17, 29, and 14 meters, respectively. The 10-meter measurement location was not feasible due to lack of access to the barge. At the distant locations of 575 meters and beyond, the measuring hydrophone was attached to a mooring buoy and retrieved at the end of pile driving.

Pile MD2-D was driven from 10:17 a.m. to 10:19 a.m., with a total drive time of 2 minutes. Water depth at the pile was about 18 meters at high level water. Measurements were conducted at two different positions: 72 and 575 meters. The water depths at the measurement locations were 15 and 29 meters, respectively. The 10-meter measurement location was not feasible due to lack of access to the barge. Due to strong currents, pile driving could not be measured over ambient levels at the 2,650-meter location. The hydrophone at the nearest location was positioned at mid-depth. At the distant location of 575 meters, the measuring hydrophone was attached to a mooring buoy and retrieved at the end of pile driving.

4.7.2 Impact Pile Driving Activities

Impact driving occurred between 1:07 p.m. and 3:08 p.m. for MD5 (total of 4,435 strikes) near low tide in water depth of 9 meters. Measurements were conducted at five positions during the impact driving: at 31 (closest possible position), 100, 590, 2,610, and 6,000 meters. The water depth at the close-in and distant positions was about 10 meters, and the hydrophones were deployed about 5 meters below the water's surface. Impact driving was conducted using the IHC S-800 hammer. Driving began with three dead blows spaced about 1 minute apart and then continuous driving occurred. Pile driving was paused about four times over the approximate 2-hour period. Hammer energy slowly increased from about 80,000 foot-pounds (108 kilojoules) to about 550,000 foot-pounds (746 kilojoules) as the pile penetrated 135 feet (41 meters) into the subsurface ground.

4.8 May 29, 2021, Pile Driving Activities

Hydroacoustic measurements were made during the vibratory installation of a 144-inch pile (MD6) followed by impact installation of the same pile. This was completed with an APE 600 Quad Beam vibratory driver and an IHC S-800 impact hammer. The air bubble curtain was operational during pile driving. Pile driving occurred during low tide.

4.8.1 Vibratory Pile Driving Activities

Pile MD6 was vibrated in from 2:58 p.m. to 3:02 p.m. The actual driving time was 1.1 minutes. Water depth at the pile was about 9 meters. There were three measurement positions: 21, m, and 115 meters from the pile. The water depths at the monitoring locations were about 7 to 9 meters. Due to strong currents, pile driving could not be measured over ambient levels at locations 600 meters and beyond. A tug associated with the construction dredging barge was near the hydrophone position at 600 meters and may have affected the sound measurements.

4.8.2 Impact Pile Driving Activities

Impact driving occurred between 4:04 p.m. and 5:45 p.m. for MD6 (total of 3,835 strikes) in water depth of 7 to 9 meters. Measurements were conducted at six positions during the impact driving: 19, 35, 115, 770, 2,630, and at 5,970 meters. The water depth at the close-in locations (19, 35, and 115 meters) was 5 meters, while the water depths at the distant locations (770, 2,630, and 5,970 meters) were 16.5, 9.5, and 7.5 meters, respectively. The hydrophones were positioned at about 1 to 1.5 meters from the bottom at each distant location. Driving with the IHC S-800 hammer began with three dead blows spaced 1 minute apart. Continuous driving followed without any pauses, as the pile was driven 126 feet (38 meters). Hammer energy increased from 82,000 foot-pounds (111 kilojoules) to 563,000 foot-pounds (763 kilojoules).

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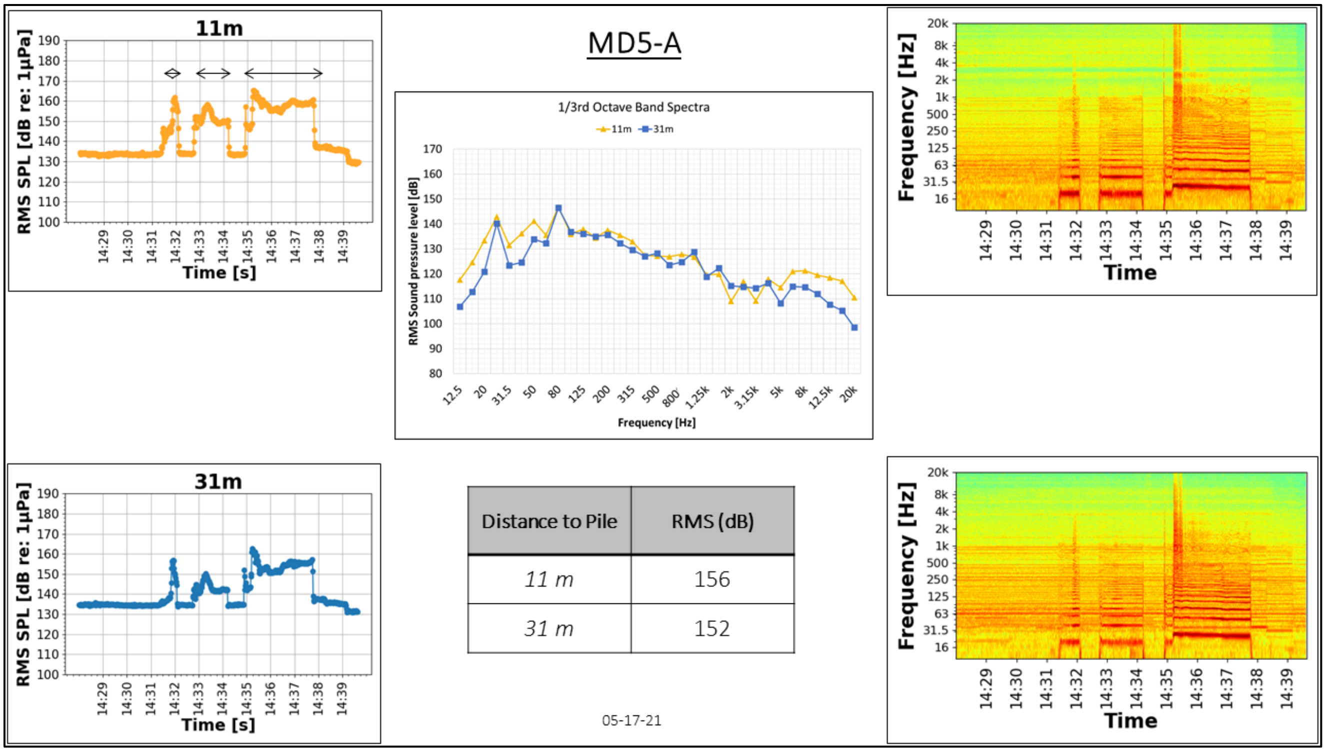
5 Measurement Results

Full summary tables showing each measured sound level metric, hammer used, and water depths are provided in Appendix A for vibratory driving and in Appendix B for impact driving. All results summarized in this chapter include RMS levels for vibratory driving, and RMS and single-strike SEL for impact driving at each position. These data are used for calculating transmission loss coefficients. Distances to the thresholds are discussed in Chapter 6.

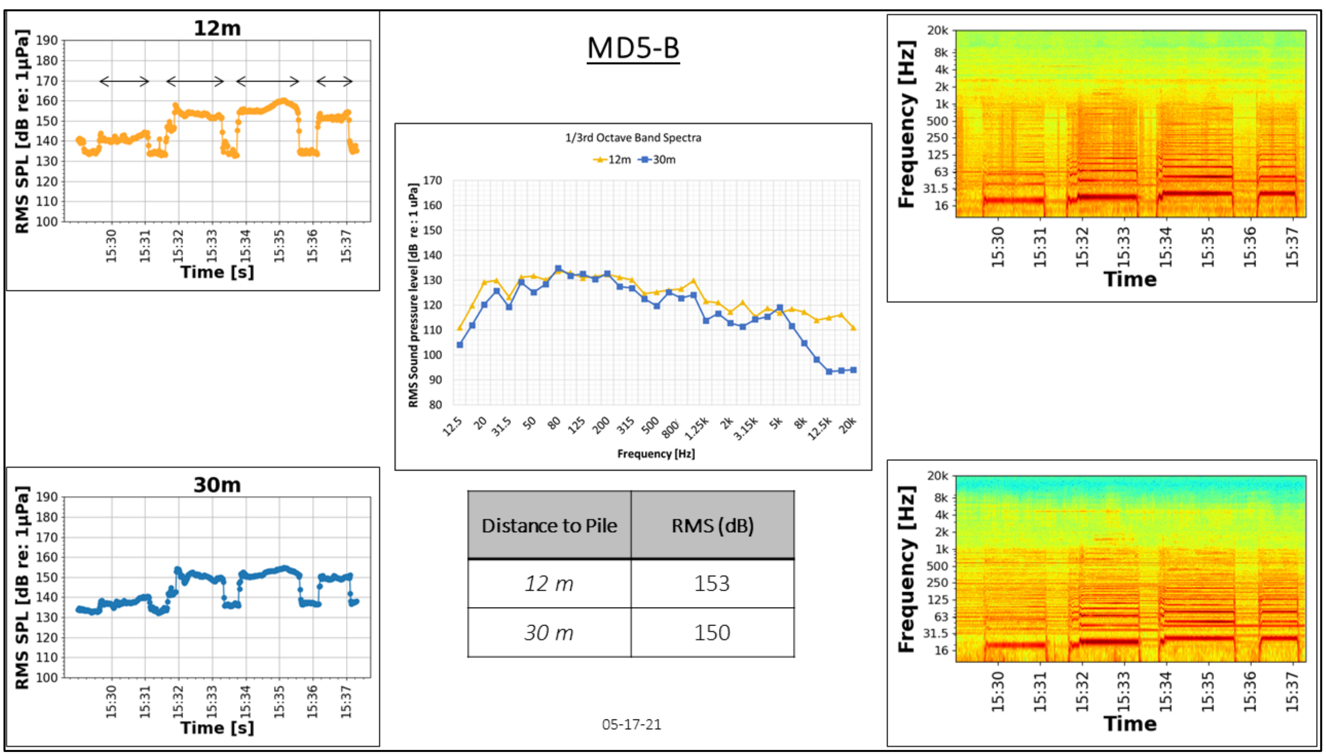
5.1 Summary of Underwater Sound Monitoring Data during 36-inch Vibratory Pile Installation

5.1.1 May 17, 2021, Measurement Results

Figure 5-1 shows the median RMS spectra (1/3-octave band center) for each measurement location, collected during the vibratory driving of piles MD5-A and MD5-B. Also shown in the figure are the RMS time histories for each monitoring location with their respective spectrograms. Table 5-1 summarizes the measured sound level (labeled as “Measured”) for the piles and includes the transmission loss coefficients calculated for the pile driving event on May 17, 2021. Standard 15Log transmission loss was used to compute distances to thresholds since not enough data were collected to compute sound transmission. Full summary tables showing each measured metric, hammer used, and water depths are provided in Appendix A.



Distance to Pile	RMS (dB)
11 m	156
31 m	152



Distance to Pile	RMS (dB)
12 m	153
30 m	150

Figure 5-1. RMS time histories, 1/3-octave band spectra, and spectrograms for each monitoring location summed from 20 to 20,000 Hz – May 17, 2021 (Piles MD5-A, MD5-B)

Table 5-1. Summary of RMS data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 17, 2021

Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB)		
			Measured [a]	TL Coefficient	Level at 10 m
14:31 to 14:38	MD5-A	11	156	15[b]	157
		31	152		
15:29 to 15:37	MD5-B	12	153	15[b]	154
		30	150		

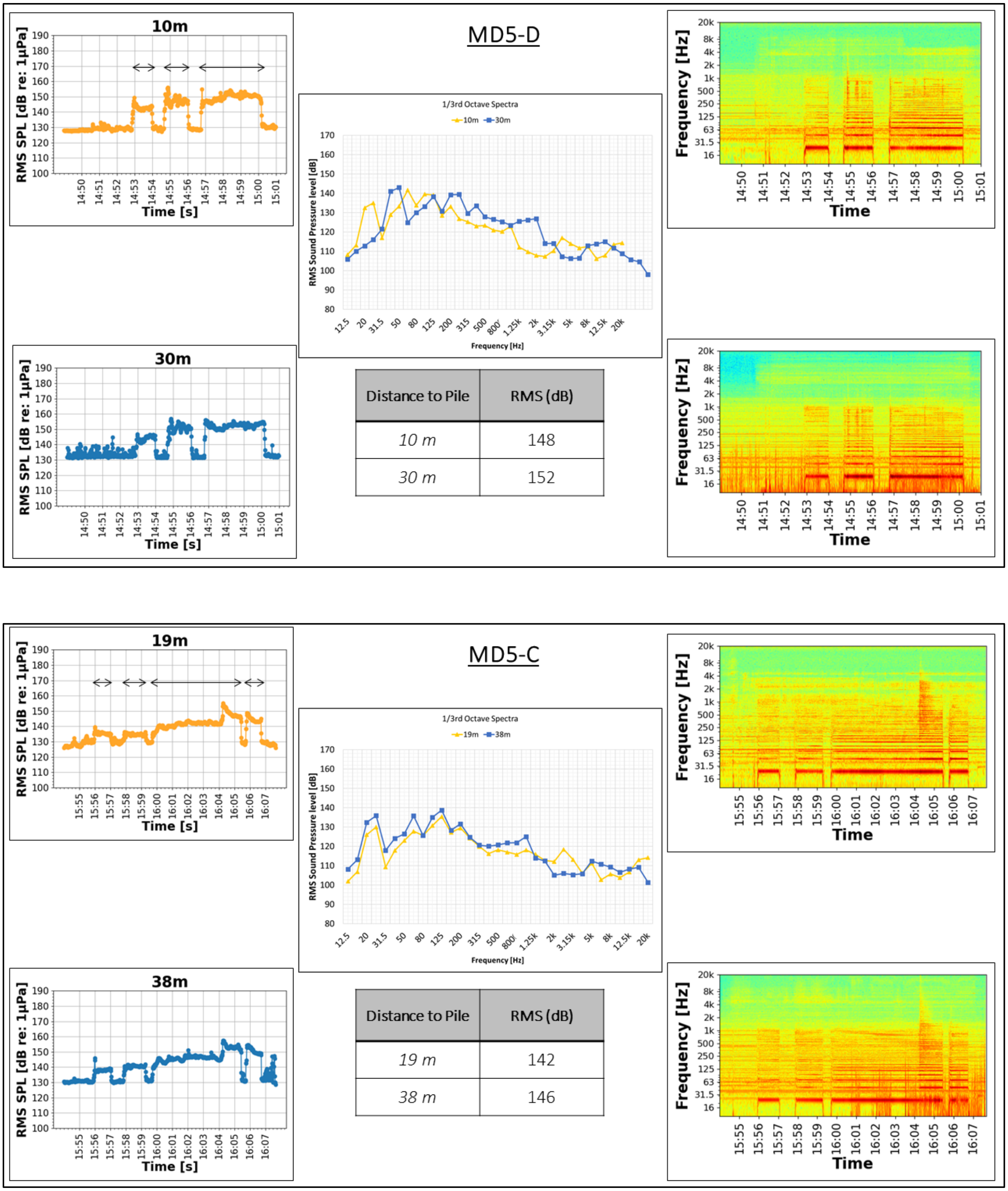
[a] Pile driving event only.

[b] Standard 15Log transmission loss was used since not enough data were collected to compute sound transmission.

Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss

5.1.2 May 18, 2021, Measurement Results

Figure 5-2 shows the median RMS spectra (1/3-octave band center) for each measurement location, collected during the vibratory driving of piles MD5-D and MD5-C. Also shown on the figure are the RMS time histories for each monitoring location, with their respective spectrograms. Table 5-2 summarizes the measured sound level (labeled as "Measured") for the piles and includes the transmission loss coefficients calculated for the pile driving event on May 18, 2021. Standard 15Log transmission loss was used since not enough data were collected to compute sound transmission. Full summary tables showing each measured metric, hammer used, and water depths are provided in Appendix A. For all 36-inch pile installations summarized in this section, the air bubble curtain was used. Levels at 10 meters were quite low and even lower than those at 30 meters. This is the only measurement where a 10-meter level was lower than a 30-meter level, which is unusual; hence, this may be indicative of the close-in (10-meter) hydrophones being affected by the air bubble flux or a more direct path of the ground-borne noise. Sound levels at both positions were quite low when compared with other results for vibratory driving.



Distance to Pile	RMS (dB)
10 m	148
30 m	152

Distance to Pile	RMS (dB)
19 m	142
38 m	146

Figure 5-2. RMS time histories, 1/3-octave band spectra, and spectrograms for each monitoring location summed from 20 to 20,000 Hz – May 18, 2021 (Piles MD5-D, MD5-C)

Table 5-2. Summary of RMS data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 18, 2021

Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB)		
			Measured [a]	TL Coefficient	Level at 10 m
14:53 to 15:00	MD5-D	10	149	15[b]	149
		30	152		
15:56 to 16:07	MD5-C	19	142	15[b]	146
		38	146		

[a] Pile driving event only.

[b] Standard 15Log transmission loss was used since not enough data were collected to compute sound transmission.

Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss.

5.1.3 May 19, 2021, Measurement Results

Figure 5-3 shows the median RMS spectra (1/3-octave band center) for each measurement location, collected during the vibratory driving of piles MD6-A and MD6-B. Also shown in the figure are the RMS time histories for each monitoring location, with their respective spectrograms. Table 5-3 summarizes the measured sound level (labeled as “Measured”) for the piles and includes the transmission loss coefficients calculated for the pile driving event on May 19, 2021. Standard 15Log transmission loss was used to compute distances to thresholds since not enough data were collected to compute sound transmission. Full summary tables showing each measured metric, hammer used, and water depths are provided in Appendix A. The first half of pile MD6-A was not measured at the 25-m location, and hence, the levels have been adjusted for the duration. This adjustment was based on applying the sound level difference between both measurement positions when simultaneous measurements were conducted to the 25-m data.

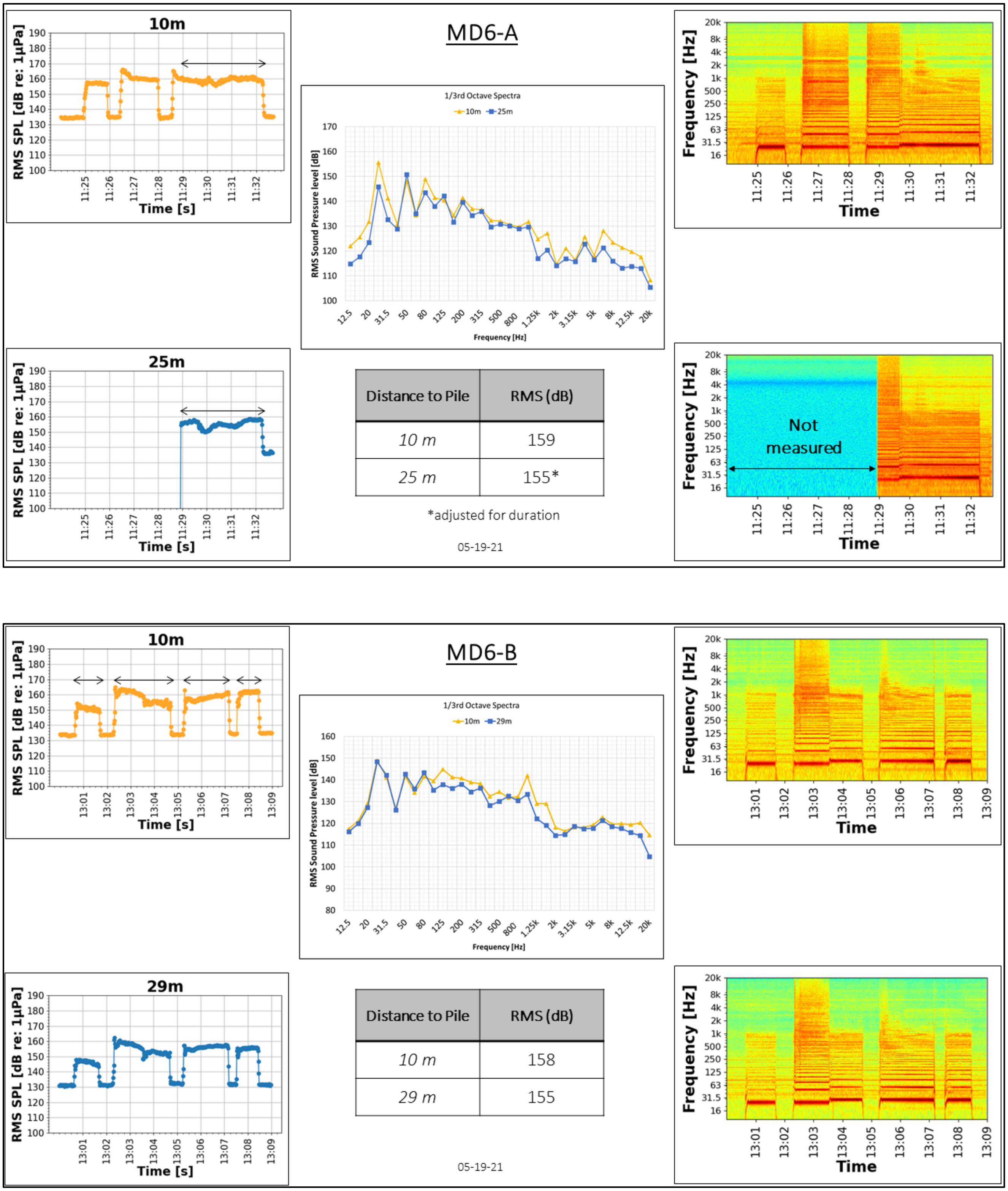


Figure 5-3. RMS time histories, 1/3-octave band spectra, and spectrograms for each monitoring location summed from 20 to 20,000 Hz – May 19, 2021 (Piles MD6-A, MD6-B)

Table 5-3. Summary of RMS data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 19, 2021

Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB)		
			Measured [a]	TL Coefficient	Level at 10 m
11:24 to 11:32	MD6-A	10	159	15[b]	159
		25	155[c]		
13:00 to 13:08	MD6-B	10	158	15[b]	158
		29	155		

[a] Pile driving event only.

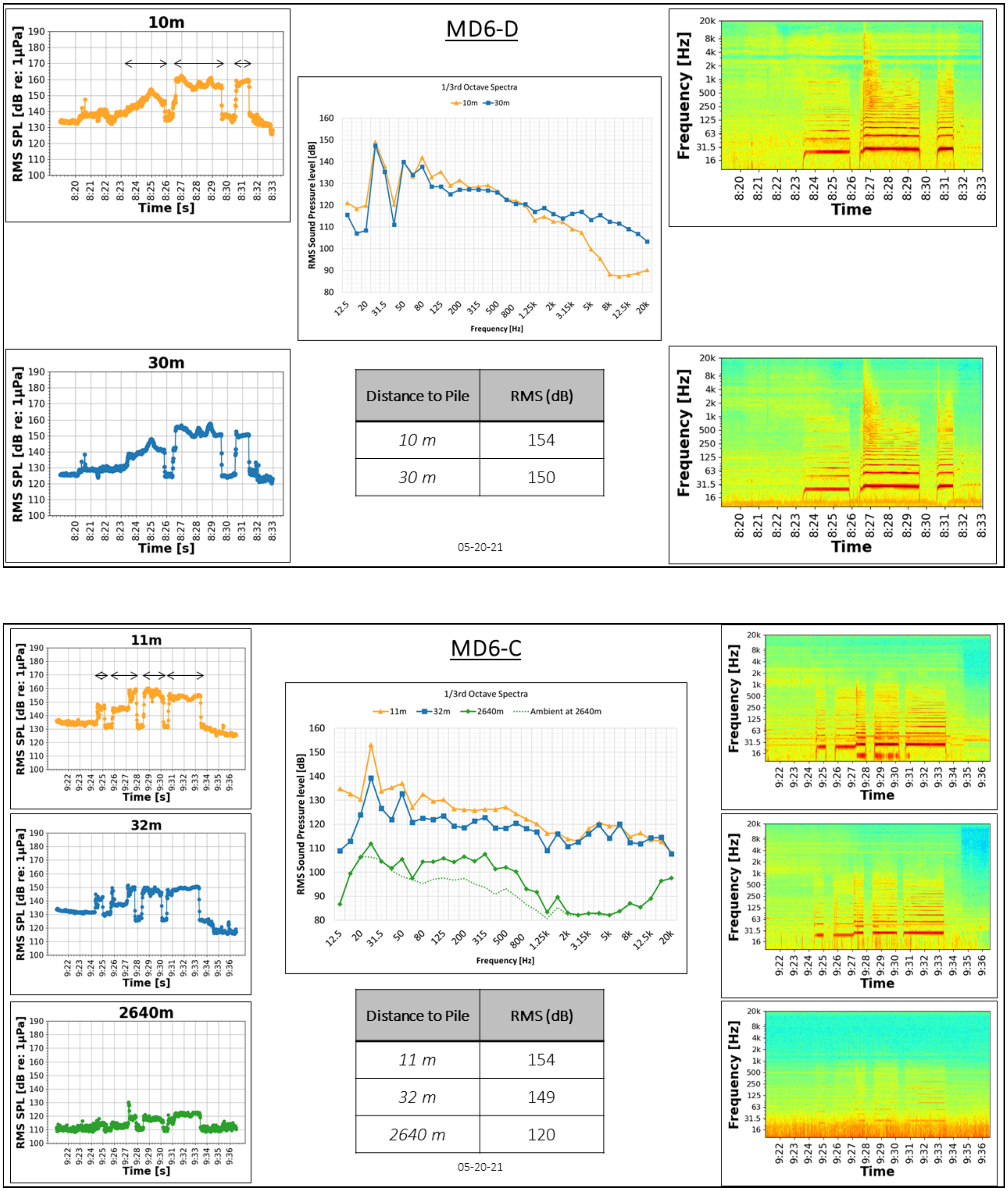
[b] Standard 15Log transmission loss was used since not enough data were collected to compute sound transmission.

[c] Adjusted for duration.

Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss.

5.1.4 May 20, 2021, Measurement Results

Figure 5-4 shows the median RMS spectra (1/3-octave band center) for each measurement location, collected during the vibratory driving of piles MD6-D and MD6-C. The increase in RMS SPL at the 10-meter location could potentially be due to denser substrate layers where the hammer meets more resistance. Variability like this is not atypical. Furthermore, the operator may change power settings while vibratory driving, which could also affect the frequency. Logs of specific vibratory driving settings are not kept. Also shown in the figure are the RMS time histories for each monitoring location, with their respective spectrograms. Table 5-4 summarizes the measured sound level (labeled as “Measured”) for the piles and includes the transmission loss coefficients calculated for the pile driving event on May 20, 2021. Standard 15Log transmission loss was used for MD6-D to compute distances to thresholds since not enough data were collected to compute sound transmission. A far-field measurement location was made for MD6-C, so a fall-off rate from the measurements was calculated for this pile. Full summary tables showing each measured metric, hammer used, and water depths are provided in Appendix A.



Distance to Pile	RMS (dB)
10 m	154
30 m	150

Distance to Pile	RMS (dB)
11 m	154
32 m	149
2640 m	120

Figure 5-4. RMS time histories, 1/3-octave band spectra, and spectrograms for each monitoring location summed from 20 to 20,000 Hz – May 20, 2021 (Piles MD6-D, MD6-C)

Table 5-4. Summary of RMS data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 20, 2021

Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB)		
			Measured [a]	TL Coefficient	Level at 10 m
08:23 to 08:31	MD6-D	10	154	15[b]	154
		30	150		
09:24 to 09:33	MD6-C	11	154	14.5	155
		32	149		
		2,640	120		

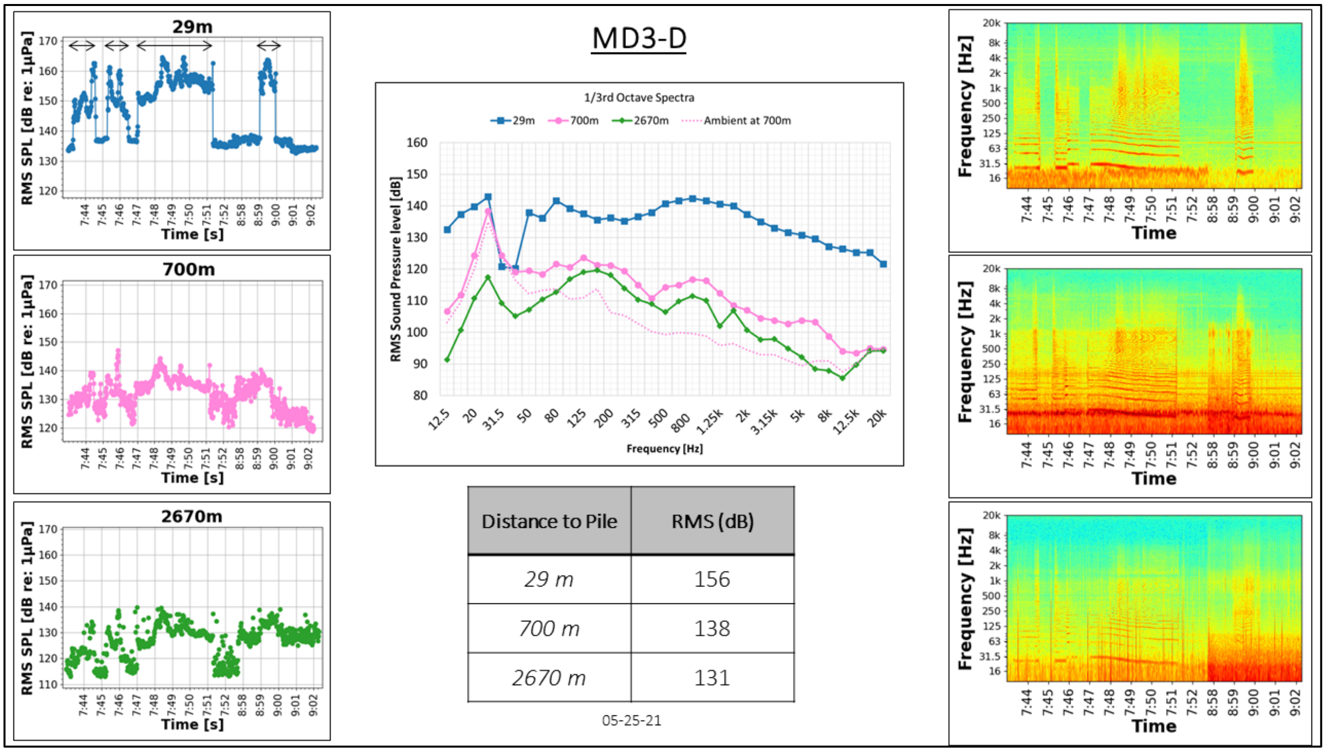
[a] Pile driving event only.

[b] Standard 15Log transmission loss was used since not enough data were collected to compute sound transmission.

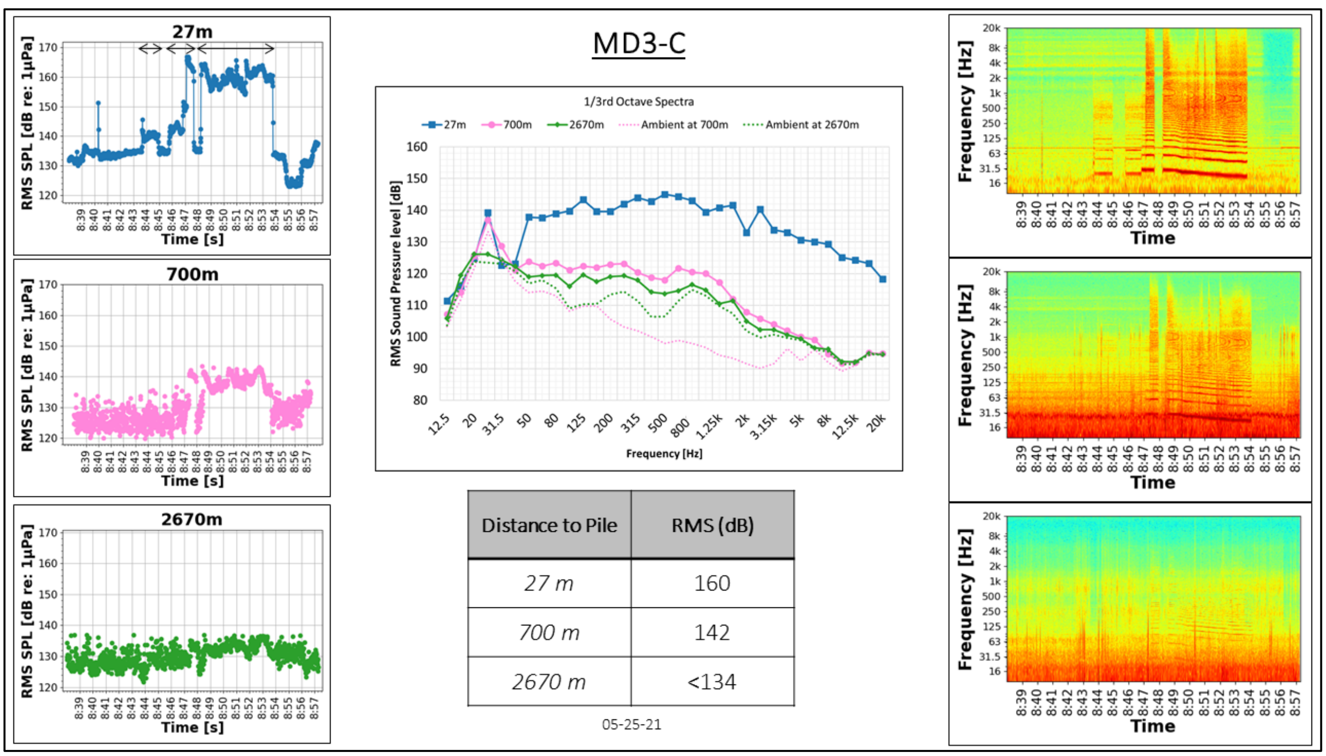
Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss.

5.1.5 May 25, 2021, Measurement Results

Figure 5-5 shows the median RMS spectra (1/3-octave band center) for each measurement location, collected during the vibratory driving of piles MD3-D and MD3-C. Also shown in the figure are the RMS time histories for each monitoring location, with their respective spectrograms. Table 5-5 summarizes the measured sound level (labeled as "Measured") for the piles and includes the transmission loss coefficients calculated for the pile driving events on May 25, 2021. Full summary tables showing each measured metric, hammer used, and water depths are provided in Appendix A. For MD3-D, the second part of the vibratory pile installation could not be measured at 2,670 meters due to high background noise as currents increased. Therefore, those data were adjusted based on the transmission loss computed across the three positions for the first part of the driving event.



Distance to Pile	RMS (dB)
29 m	156
700 m	138
2670 m	131



Distance to Pile	RMS (dB)
27 m	160
700 m	142
2670 m	<134

Figure 5-5. RMS time histories, 1/3-octave band spectra, and spectrograms for each monitoring location summed from 20 to 20,000 Hz – May 25, 2021 (Piles MD3-D, MD3-C)

Table 5-5. Summary of RMS data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 25, 2021

Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB)		
			Measured [a]	TL Coefficient	Level at 10 m
07:43 to 07:52; 08:59 to 09:00	MD3-D	29	156	13.5	161
		700	138		
		2,670	131[b]		
08:39 to 08:54	MD3-C	27	160	15[c]	166
		700	142		
		2,670	<134		

[a] Pile driving event only.

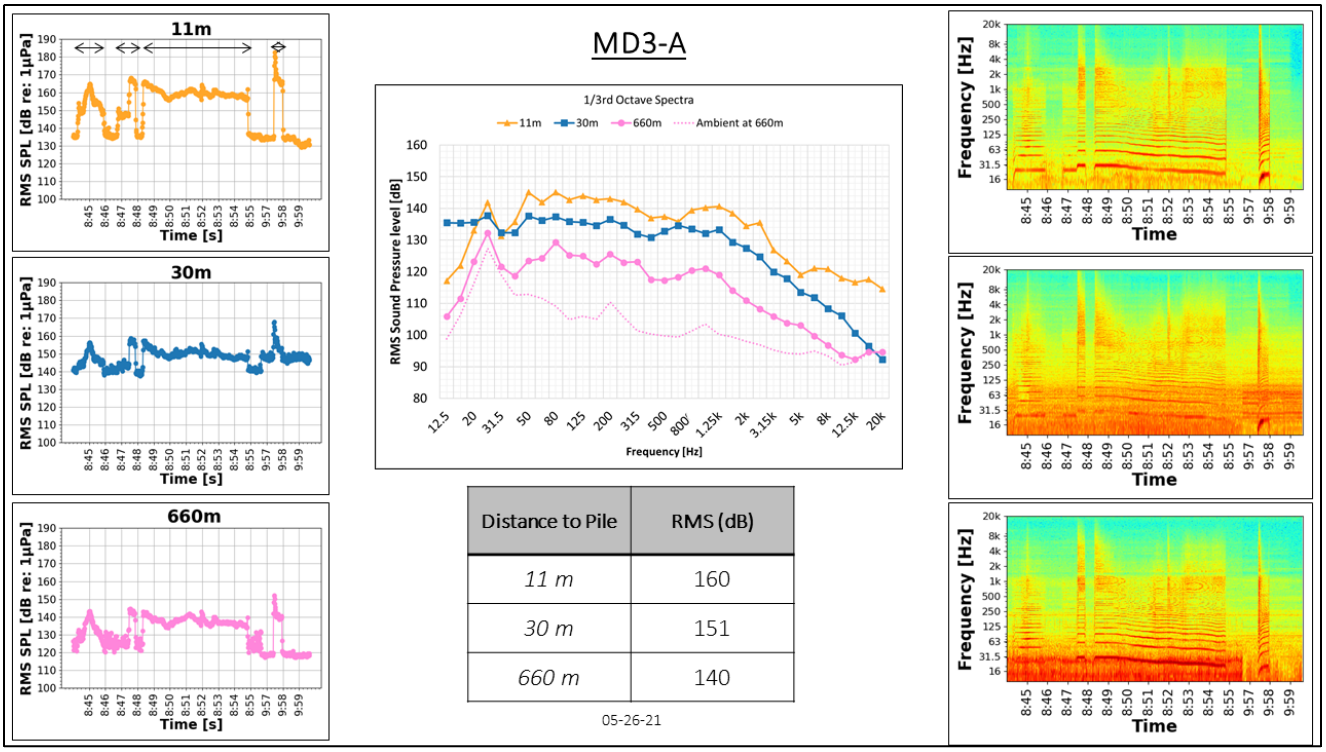
[b] Adjusted based on the TL computed across the three positions for the first part of the driving event.

[c] Standard 15Log transmission loss was used since not enough data were collected to compute sound transmission.

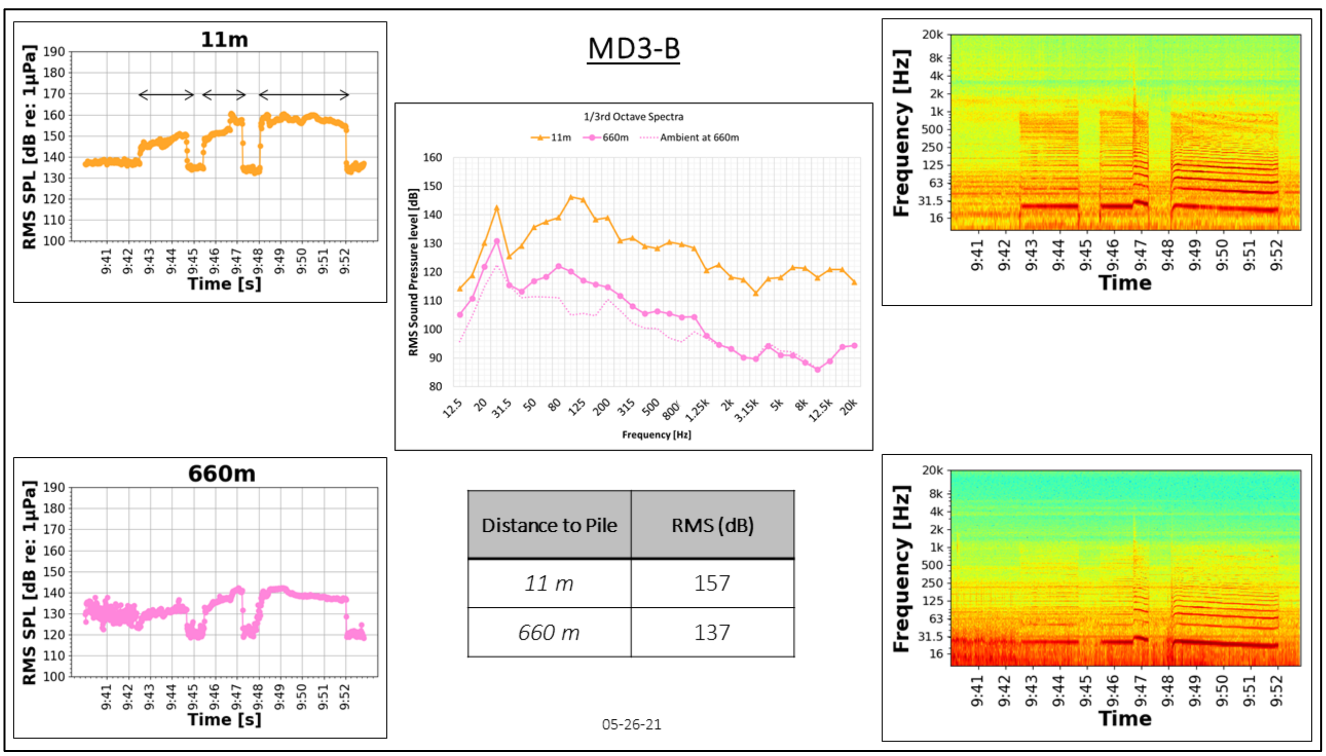
Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss.

5.1.6 May 26, 2021, Measurement Results

Figure 5-6 shows the median RMS spectra (1/3-octave band center) for each measurement location, collected during the vibratory driving of piles MD3-A and MD3-B. Also shown on the figure are the RMS time histories for each monitoring location, with their respective spectrograms. Table 5-6 summarizes the measured sound level (labeled as “Measured”) for the piles and includes the transmission loss coefficients calculated for the pile driving event on May 26, 2021. Full summary tables showing each measured metric, hammer used, and water depths are provided in Appendix A.



Distance to Pile	RMS (dB)
11 m	160
30 m	151
660 m	140



Distance to Pile	RMS (dB)
11 m	157
660 m	137

Figure 5-6. RMS time histories, 1/3-octave band spectra, and spectrograms for each monitoring location summed from 20 to 20,000 Hz – May 26, 2021 (Piles MD3-A, MD3-B)

Table 5-6. Summary of RMS data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 26, 2021

Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB)		
			Measured [a]	TL Coefficient	Level at 10 m
08:44 to 08:55; 09:57 to 09:58	MD3-A	11	160	10.5	159
		30	151		
		660	140		
09:43 to 09:52	MD3-B	11	157	15[b]	158
		660	137		

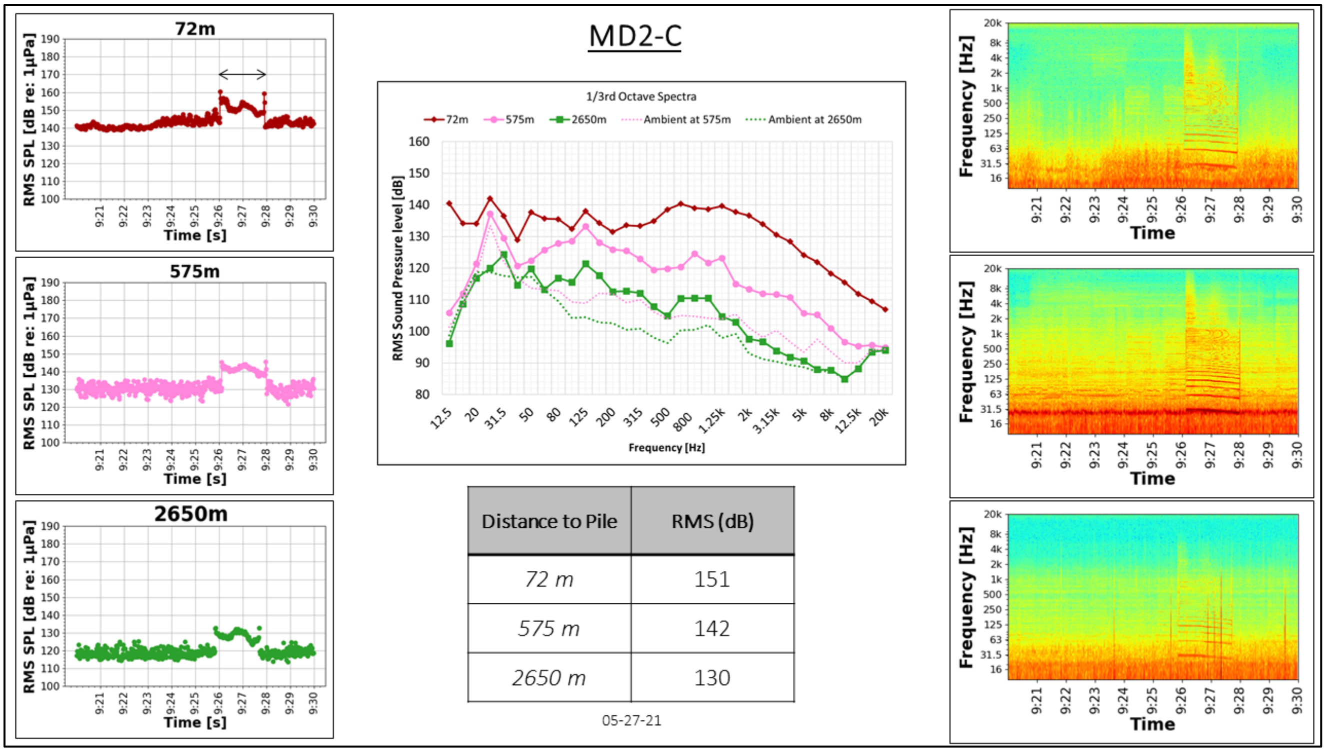
[a] Pile driving event only.

[b] Standard 15Log transmission loss was used since not enough data were collected to compute sound transmission. Note that this method approximates levels. In this case, the 10-meter level is computed slightly higher than the measured level at 11 meters because of the computed TL.

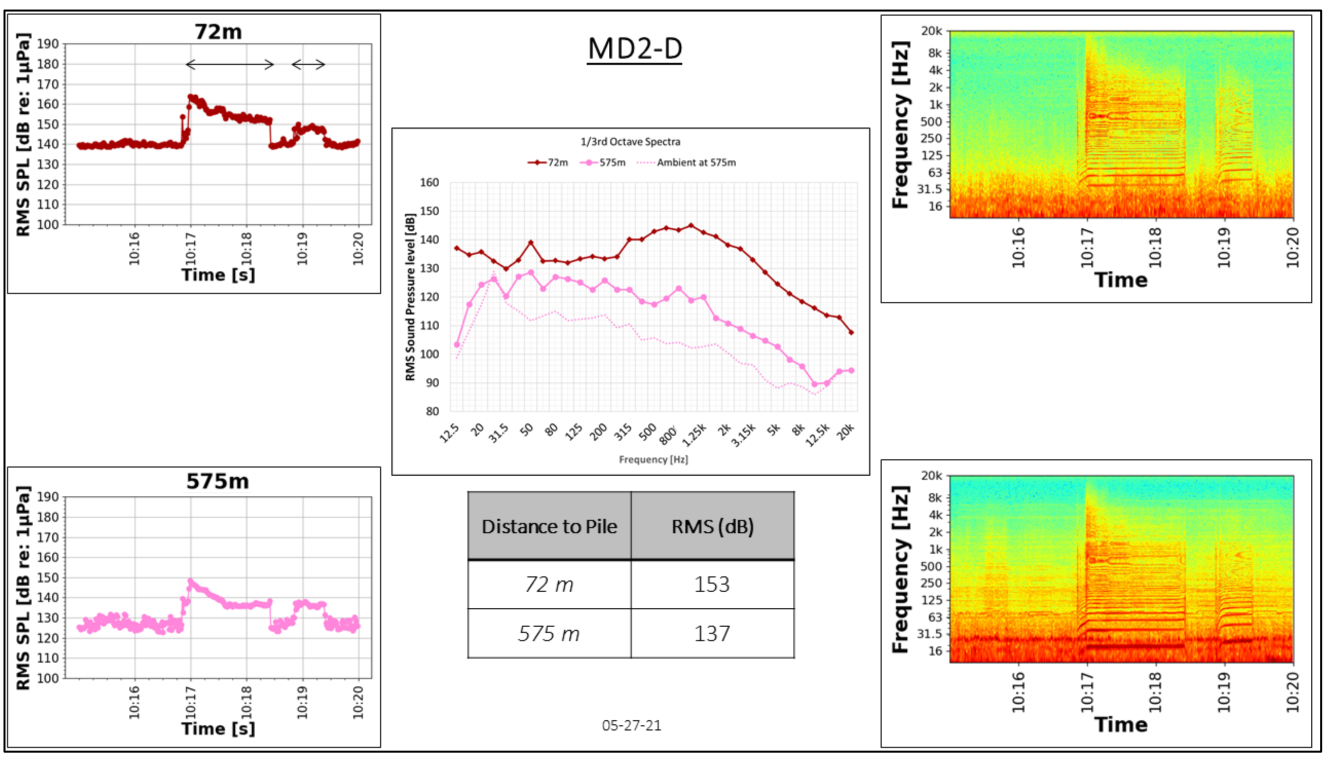
Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss.

5.1.7 May 27, 2021, Measurement Results

Figure 5-7 shows the median RMS spectra (1/3-octave band center) for each measurement location, collected during the vibratory driving of piles MD2-C and MD2-D. Also shown in the figure are the RMS time histories for each monitoring location, with their respective spectrograms. Table 5-7 summarizes the measured sound level (labeled as "Measured") for the piles and includes the transmission loss coefficients calculated for the pile driving event on May 27, 2021. Full summary tables showing each measured metric, hammer used, and water depths are provided in Appendix A.



Distance to Pile	RMS (dB)
72 m	151
575 m	142
2650 m	130



Distance to Pile	RMS (dB)
72 m	153
575 m	137

Figure 5-7. RMS time histories, 1/3-octave band spectra, and spectrograms for each monitoring location summed from 20 to 20,000 Hz – May 27, 2021 (Piles MD2-C, MD2-D)

Table 5-7. Summary of RMS data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 27, 2021

Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB)		
			Measured [a]	TL Coefficient	Level at 10 m
09:24 to 09:28; 10:11 to 10:12	MD2-C	72	151	13.2	163
		575	142		
		2,650	130		
10:17 to 10:19	MD2-D	72	153	15[b]	166
		575	137		

[a] Pile driving event only.

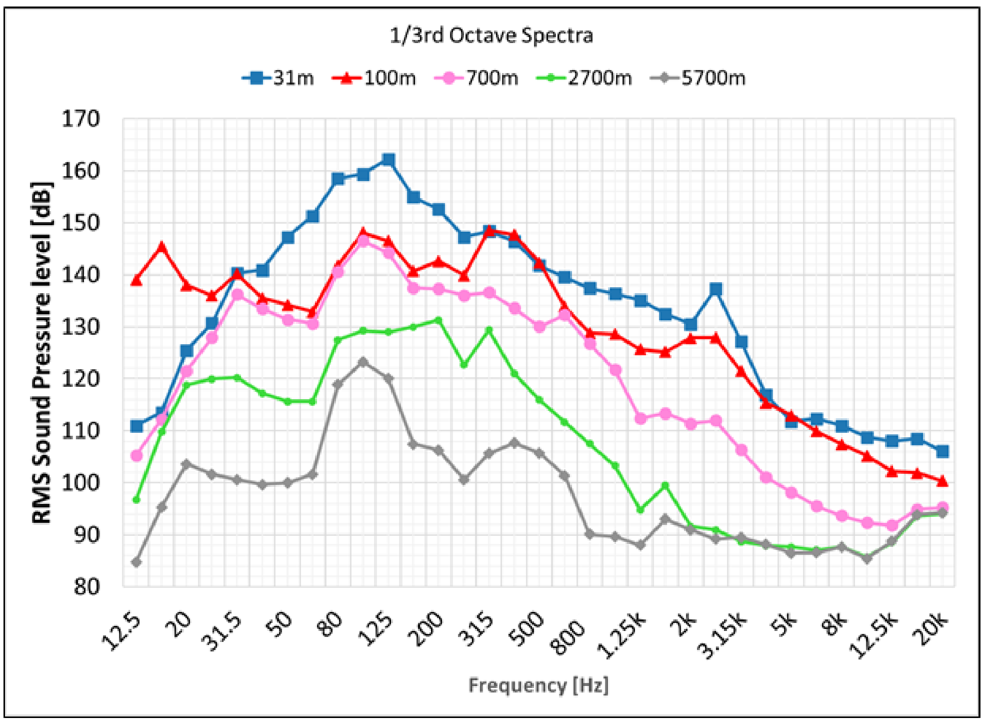
[b] Standard 15Log transmission loss was used since not enough data were collected to compute sound transmission.

Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss.

5.2 Summary of Underwater Sound Monitoring Data during all 144-inch Vibratory Pile Installation

5.2.1 May 26, 2021, Measurement Results

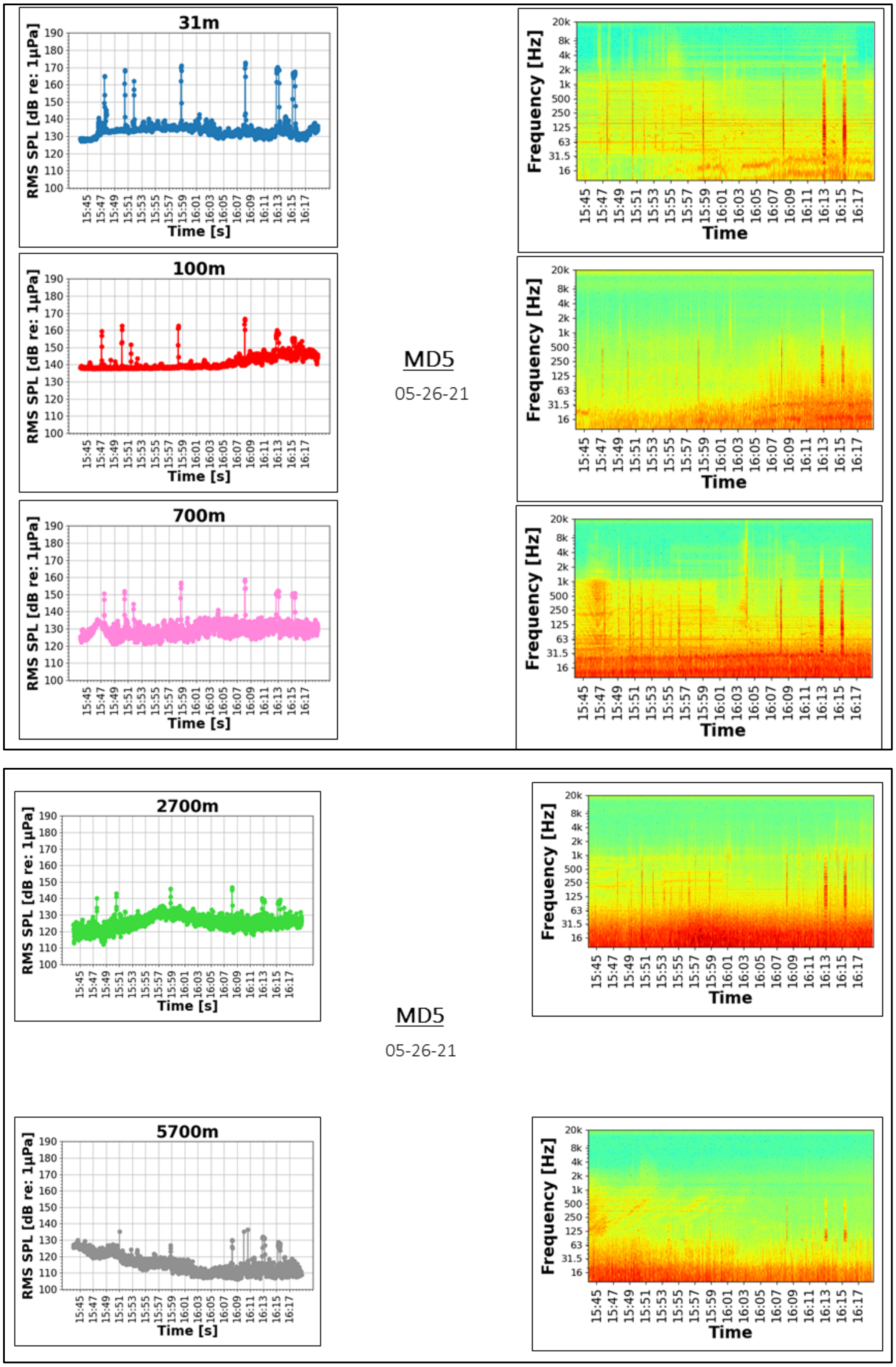
A single monopile (MD5) was never actually driven with a vibratory driver but was “shaken” several times in an attempt to attach the vibratory driver on May 26, 2021. This was a unique operation and not repeated during the in-water work. Sound levels were detectable out to 6 km. Figure 5-8 (a) shows the median RMS spectra for each measurement location, collected during the vibratory shaking of the pile. Figure 5-8 (b) shows the RMS time histories for each monitoring location and the corresponding spectrograms. Table 5-8 summarizes the measured sound level (labeled as “Measured”) for the pile and includes the transmission loss coefficient calculated. Summary tables showing each measured metric, hammer used, and water depths are provided in Appendix B.



MD5 05-26-21

Distance to Pile	RMS (dB)
31 m	167
100 m	155
700 m	151
2700 m	138
5700 m	126

(a)



(b)

Figure 5-8. (a) One-third-octave band spectra, (b) RMS time histories, and spectrograms for each monitoring location summed from 20 to 20,000 Hz – May 26, 2021 (Pile MD5)

Table 5-8. Summary of RMS data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 26, 2021

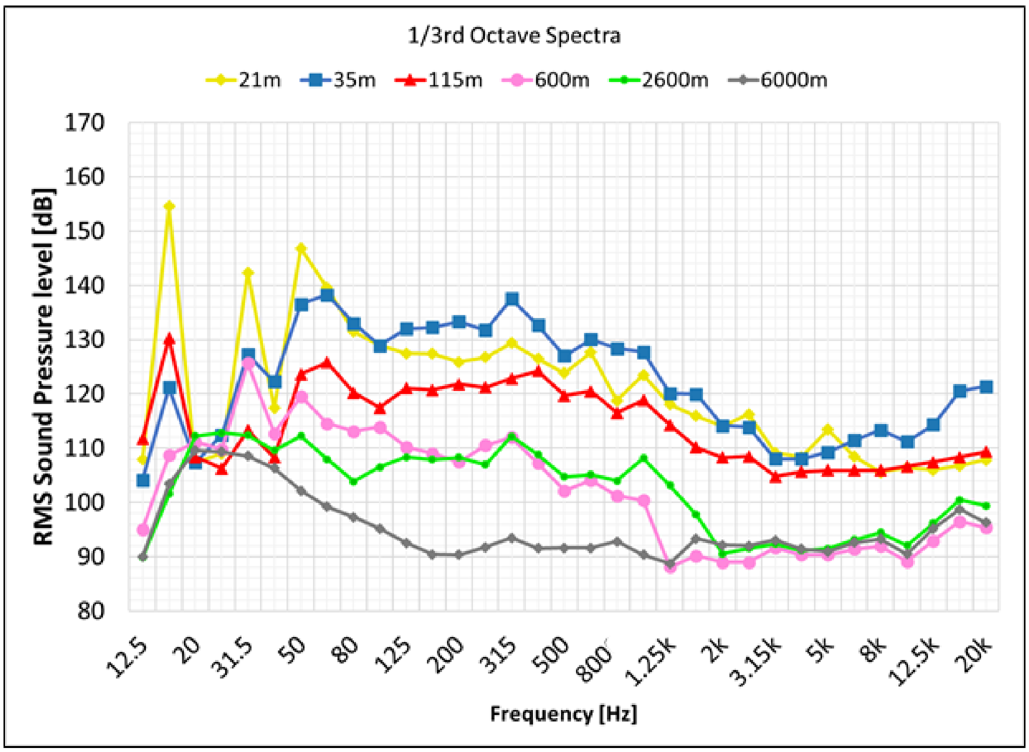
Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB)		
			Measured [a]	TL Coefficient	Level at 10 m
15:46; 15:49; 15:50; 15:57; 16:07; 16:12 to 16:13; 16:14 to 16:15	MD5	31	167	16.0	175
		100	155		
		700	151		
		2,700	138		
		5,700	126		

[a] Pile driving event only.

Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss.

5.2.2 May 29, 2021, Measurement Results

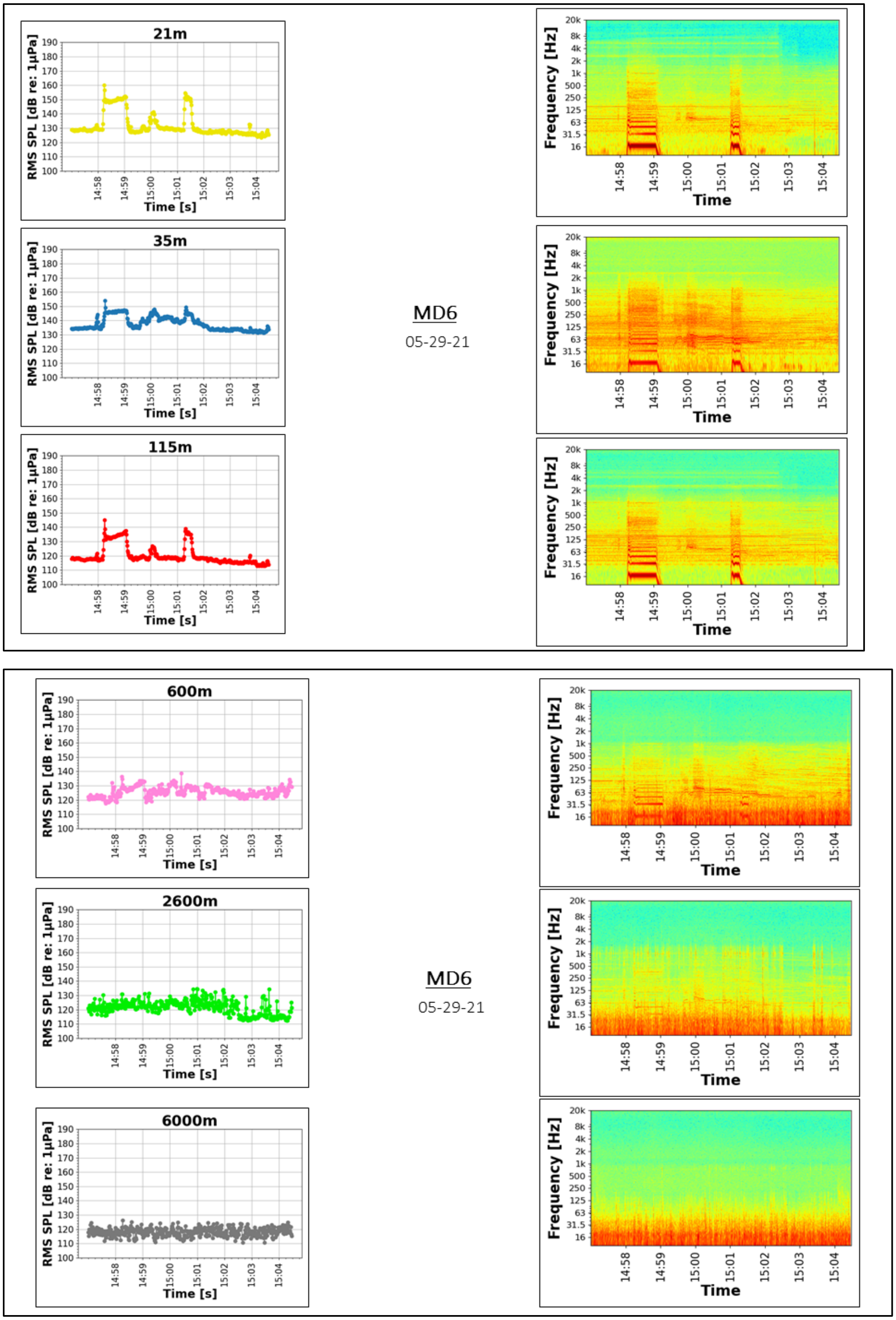
One 144-inch pile (MD6) was vibrated in on May 29, 2021. Figure 5-9 (a) shows the median RMS spectra for each measurement location, collected during the vibratory driving of the pile. Figure 5-9 (b) shows the RMS time histories for each monitoring location and the spectrograms corresponding to the same. Table 5-9 summarizes the measured sound level (labeled as "Measured") for the pile and includes the transmission loss coefficient calculated. Due to strong currents, the relatively quiet piling sounds at locations beyond 600 meters could not be detected and hence are not included in calculating the transmission loss coefficient. Other sounds from construction tugs operating near the 600-meter position also contributed to high background levels. Vibratory sounds were not audible in recordings at 2,600 and 6,000 meters. Summary tables showing each measured metric, hammer used, and water depths are provided in Appendix B.



MD6 05-29-21

Distance to Pile	RMS (dB)
21 m	150
35 m	146
115 m	134
600 m	<130
2600 m	<124
6000 m	<118

(a)



(b)

Figure 5-9. (a) One-third-octave band spectra, (b) RMS time histories, and spectrograms for each monitoring location summed from 20 to 20,000 Hz – May 29, 2021 (Pile MD6)

Table 5-9. Summary of RMS data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 29, 2021

Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB)		
			Measured [a]	TL Coefficient	Level at 10 m
14:58 to 15:02	MD6	21	150	14.1	153
		35	146		
		115	134		
		600	<130		
		2,600	<124[b]		
		6,000	<118[b]		

[a] Pile driving event only.

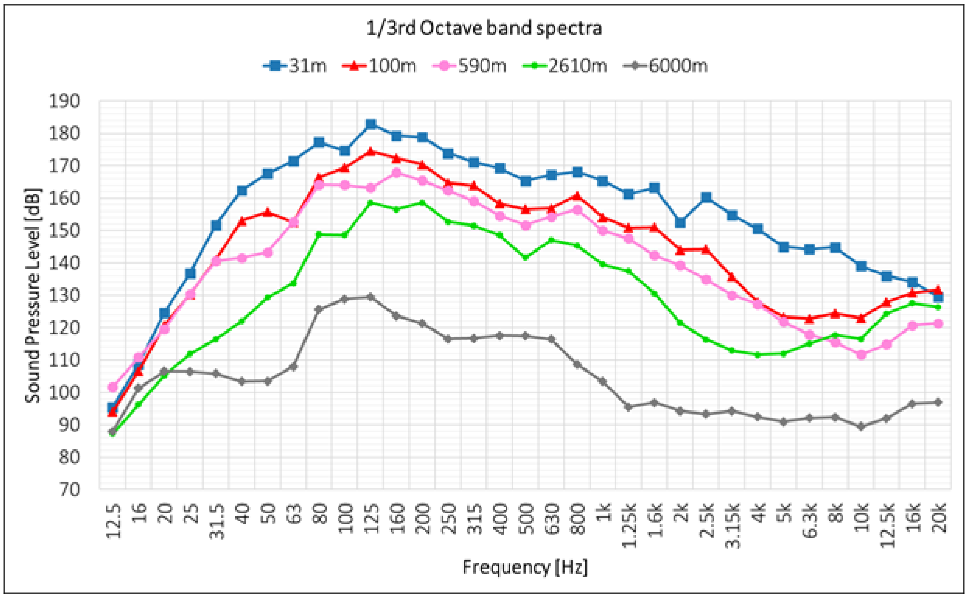
[b] Not included in analysis.

Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss.

5.3 Summary of Underwater Sound Monitoring Data during Impact Pile Driving

5.3.1 May 27, 2021, Measurement Results

A 144-inch pile (MD5) was driven on May 27, 2021, using an impact hammer. Figure 5-10 (a) shows the median spectra for each measurement location matched with the duration of the 31-meter measurement location. Figure 5-10 (b) shows the peak, RMS90%, single-strike SEL, and SEL_{cum} levels for each impact throughout the duration, along with the corresponding spectrograms and single-strike SEL time histories for each monitoring location. Table 5-10 summarizes the median RMS90% and the median single-strike SEL levels for the pile impacts, as well as the transmission loss coefficients calculated. The 31-meter location failed to record the entire duration of the impact pile driving activity, which is pointed out on Figure 5-10 (b). Backup systems measured the peak and SEL at this position but did not provide recordings for analysis of pulse RMS levels. The measurements at 100 meters were discontinued at 15:06 when pile driving was initially completed. At that time, the observer retrieved the equipment as a work barge moved into the area. Pile driving unexpectedly had to be resumed for a brief period of about 3 minutes.



MD5

05-27-21

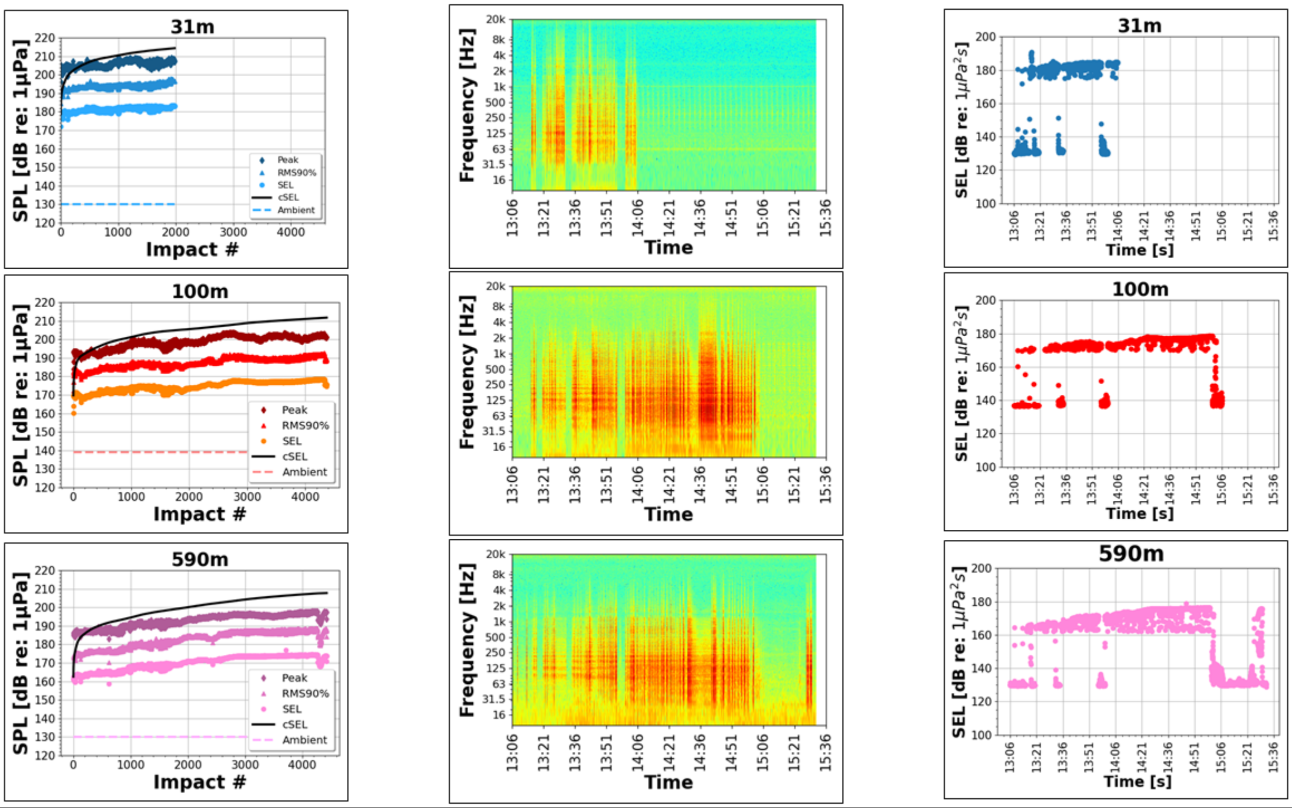
Distance to Pile	RMS90% (dB)
31 m	194
100 m	185[a]
590 m	179[a]
2610 m	168[a]
6000 m	141[a]

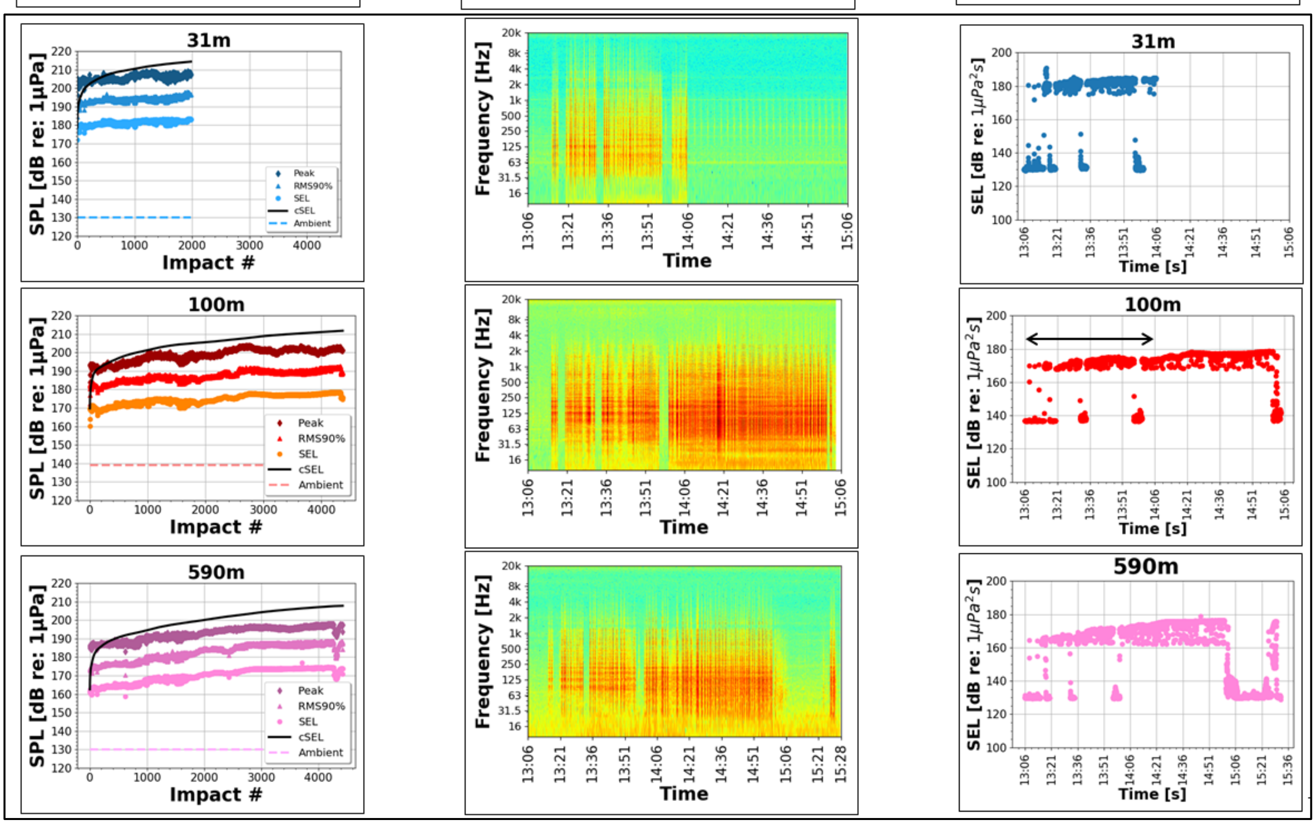
[a] ***31m matching segment***

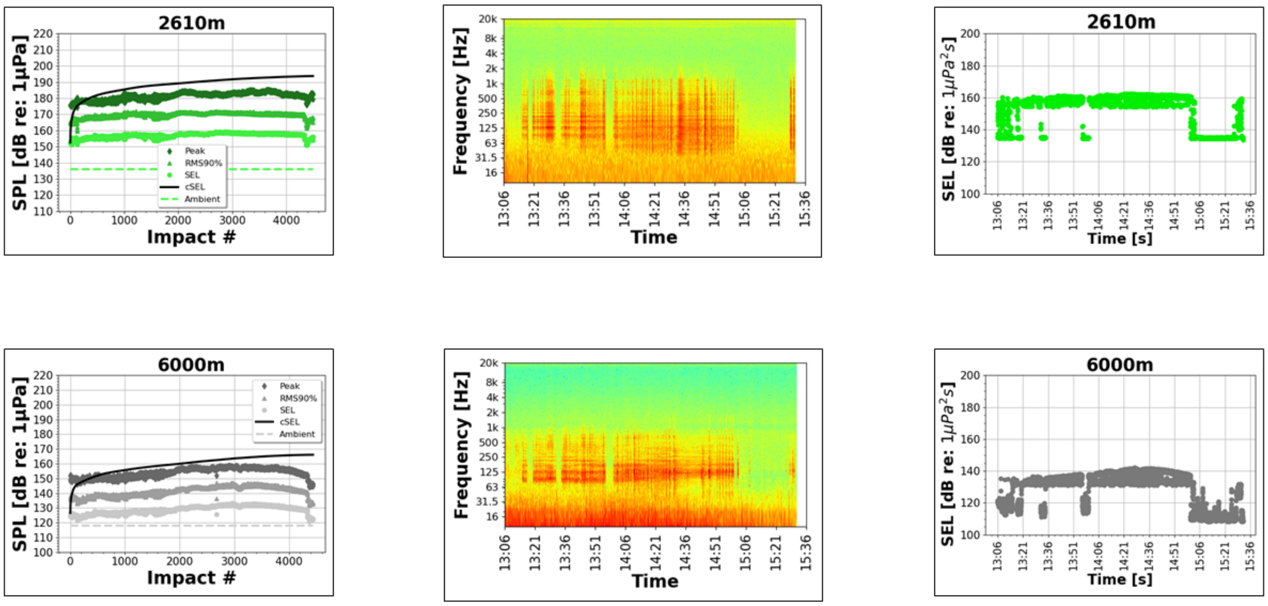
Distance to Pile	RMS90% (dB)
31 m	194[b]
100 m	187[b]
590 m	184[b]
2610 m	169[b]
6000 m	144[b]

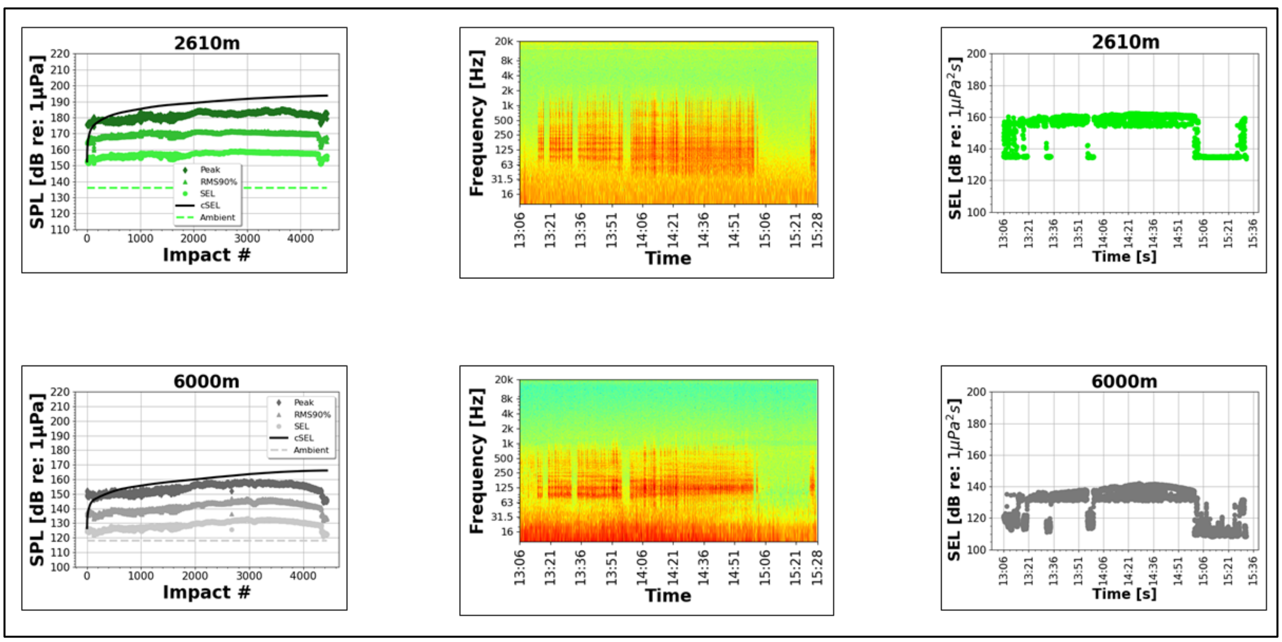
[b] ***Full duration of measurement***

(a)


31m
SPL [dB re: 1μPa]
Impact #
Peak
RMS90%
SEL
cSEL
Ambient
Frequency [Hz]
Time
SEL [dB re: 1μPa²s]
Time [s]
100m
590m


31m
SPL [dB re: 1μPa]
Impact #
Peak
RMS90%
SEL
cSEL
Ambient
Frequency [Hz]
Time
SEL [dB re: 1μPa²s]
Time [s]
100m
590m





(b)

Figure 5-10. (a) One-third-octave band spectra, (b) peak, RMS90%, single-strike SEL, and cSEL levels for each impact, and the corresponding spectrograms and single-strike SEL time histories for each monitoring location summed from 20 to 20,000 Hz – May 27, 2021 (Pile MD5)

Table 5-10. Summary of peak, RMS90% and single-strike SEL data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 27, 2021

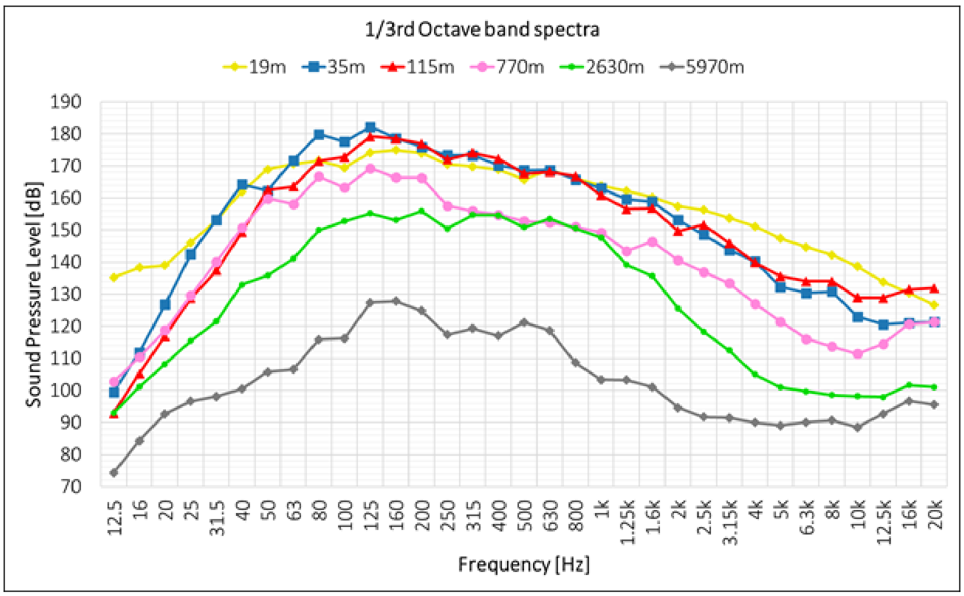
Time	Pile ID	Distance to Pile from Hydrophone (m)	Full Event					31-m Matching Segment				
			Peak (dB)[a]	RMS90% (dB)[a]	SEL (dB)[a]	TL RMS	RMS Level at 10 m	Peak (dB)[a]	RMS90% (dB)[a]	SEL (dB)[a]	TL RMS	RMS Level at 10 m
13:07 to 15:28	MD5	31	205	191	181	17.8	205	206	194	181	19.7	207
		100	199	187	175			196	185	173		
		590	194	184	170			190	179	166		
		2,610	180	169	157			178	168	155		
		6,000	154	144	135			151	141	132		

[a] Pile driving event only.

Note: dB = decibels; m = meters; RMS = root mean square; SEL = sound exposure level; TL = transmission loss.

5.3.2 May 29, 2021, Measurement Results

A 144-inch pile (MD6) was driven on May 29, 2021, using an impact hammer. Figure 5-11 (a) shows the median RMS90% spectra for each measurement location. Figure 5-11 (b) shows the peak, RMS90%, single-strike SEL, and cSEL levels for each impact throughout the duration, along with the corresponding spectrograms and single-strike SEL time histories for each monitoring location. Table 5-11 summarizes the median RMS90% and the median single-strike SEL levels for the pile impacts as well as the transmission loss coefficients calculated. An air bubble curtain was used during the impact installation of pile MD6.

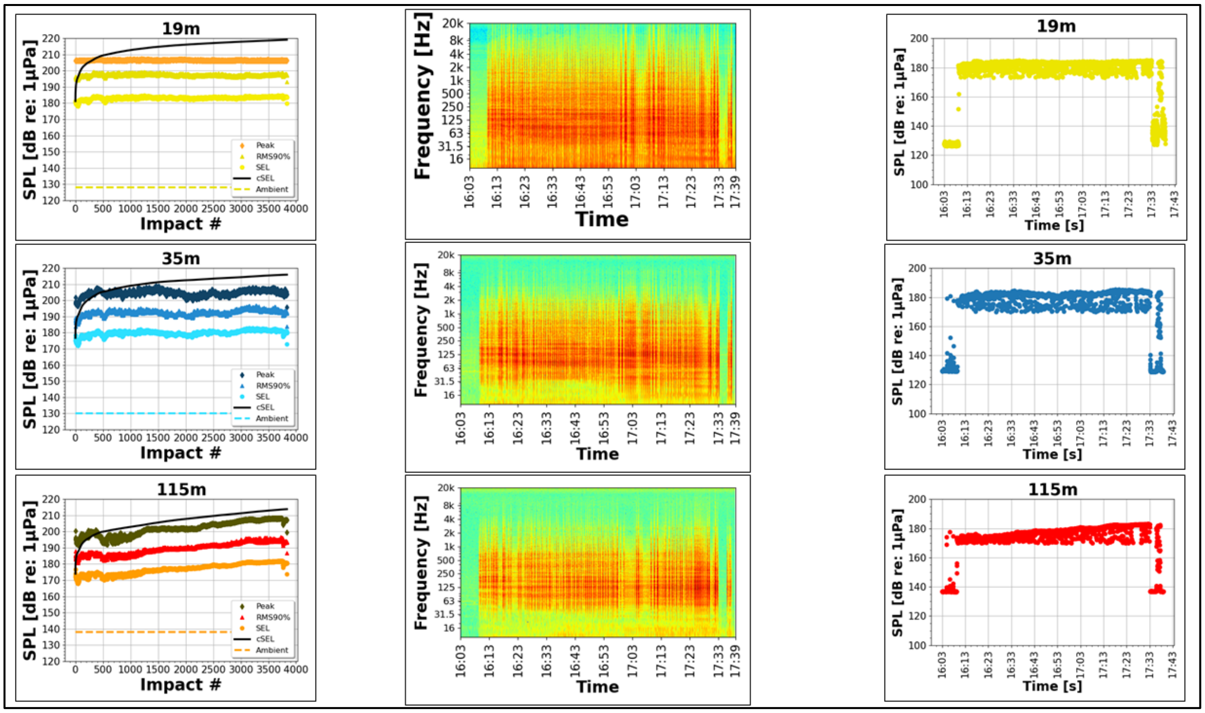


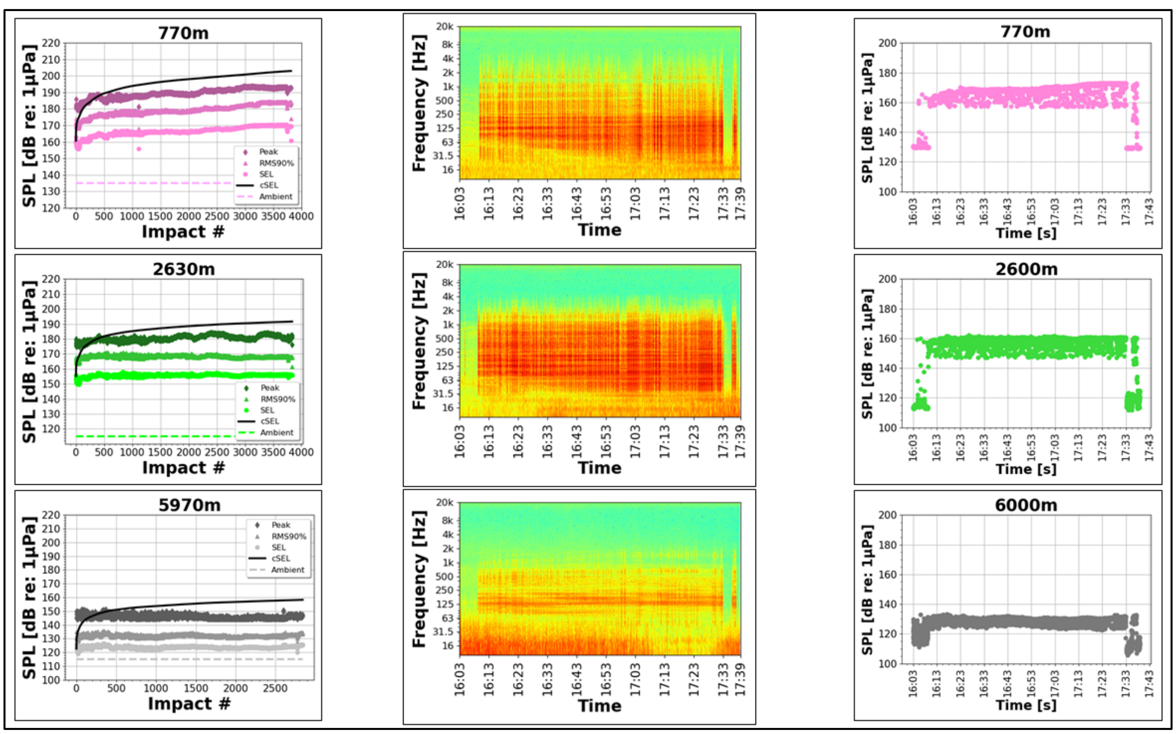
MD6

05-29-21

Distance to Pile	RMS90% (dB)
19 m	197
35 m	193
115 m	190
770 m	179
2630 m	168
5970 m	135

(a)





(b)

Figure 5-11. (a) One-third-octave band spectra, (b) peak, RMS90%, single-strike SEL, and cSEL levels for each impact, and the corresponding spectrograms and single-strike SEL time histories for each monitoring location summed from 20 to 20,000 Hz – May 29, 2021 (Pile MD6)

Table 5-11. Summary of peak, RMS90% and single-strike SEL data, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on May 29, 2021

Time	Pile ID	Distance to Pile from Hydrophone (m)	Peak (dB)[a]	RMS90% (dB)[a]	SEL (dB)[a]	TL Coefficient for RMS	RMS Level at 10 m
16:04 to 17:45	MD6	19	208	197	183	20.4	207
		35	205	193	180		
		110	202	190	178		
		770	189	179	166		
		2,630	180	168	157		
		5,970	146	135	126		

[a] Impacts only.

Note: dB = decibels; m = meters; RMS = root mean square; TL = transmission loss.

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6 Discussion

6.1 Thirty-six-inch Vibratory Pile Driving Propagation and Threshold Distances

6.1.1 Unweighted Transmission Loss and Distances to the Level B Threshold

Measurements were made for 14 of the 36-inch temporary template piles installed with a bubble curtain operating during May 2021. The driving times ranged from 2 to 9.2 minutes. All 36-inch temporary template piles were driven using an APE 300-6 vibratory hammer.

Table 6-1 summarizes the transmission loss coefficients, the coefficients of determination (R^2) for the trendlines, the estimated RMS levels at 10 meters, and the distance to the Level B threshold of 122.2 dB for individual piles. The data points and trendlines for each individual pile are plotted on Figure 6-1. Note that only data points that represented "clean" acoustic signals from pile driving were used.

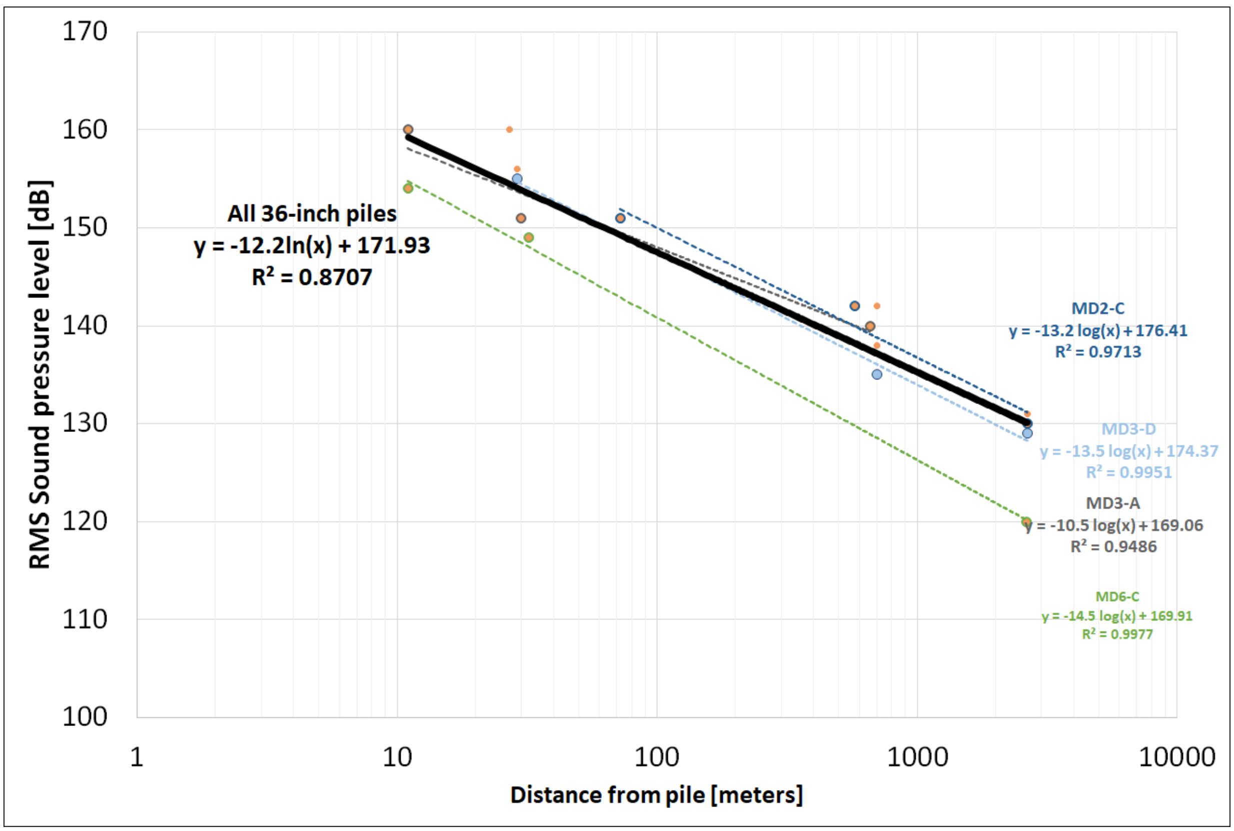

Figure 6-1. Data points and trendlines for all 36-inch temporary template piles installed with vibratory hammer

Table 6-1. Summary of unweighted transmission loss calculations for 36-inch temporary template piles installed with vibratory hammer and bubble curtain

Pile ID	Date	Duration of Drive	Transmission Loss Coefficient	R^2 Value	Computed RMS Level at 10 m	Distance to Level B Threshold (122.2 dB)
MD5-A	5/17/2021	5.0 minutes	--[a]	--	157	2.0 km
MD5-B		5.9 minutes	--[a]	--	154	1.4 km
MD5-D	5/18/2021	5.8 minutes	--[a]	--	149	0.6 km
MD5-C		9.2 minutes	--[a]	--	146	0.4 km
MD6-A	5/19/2021	6.1 minutes	--[a]	--	159	2.8 km
MD6-B		4.9 minutes	--[a]	--	158	2.4 km
MD6-D	5/20/2021	6.3 minutes	--[a]	--	154	1.3 km
MD6-C		7.2 minutes	14.5	0.9977	155	1.9 km
MD3-D	5/25/2021	7.6 minutes	13.5	0.9951	161	7.6 km
MD3-C		9.0 minutes	--[a]	--	166	8.9 km
MD3-A	5/26/2021	9.1 minutes	10.5	0.9486	159	31.9 km[b]
MD3-B		7.7 minutes	--[a]	--	158	2.3 km
MD2-C	5/27/2021	4.6 minutes	13.2	0.9713	163	12.8 km
MD2-D		2.0 minutes	--[a]	--	166	8.1 km
Mean:		6.5 minutes	12.9	0.9782	158	6.0 km
Median:		6.2 minutes	13.35	0.9832	158	2.35 km
Regression Using All Points:			12.2	0.8707	160	11.8 km
Using Far-Field Points[c] Only:			16.3	0.8140	168	6.6 km

[a] Standard 15Log transmission loss was used since not enough data were collected to compute sound transmission.

[b] TL coefficient is 10.5, hence the larger Level B distance.

[c] Far-field points include points located greater than the 30- to 32-meter measurement.

Note: dB = decibels; km = kilometers; R^2 = coefficient of determination; RMS = root mean square; TL = transmission loss.

6.1.2 Marine Mammal Weighting Transmission Loss and Distances to the Level A Thresholds

The marine mammal weightings were applied to the unweighted frequency spectra from Chapter 5, and the overall weighted levels for each marine mammal weighting category, between 20 and 20,000 Hz, were used to determine the transmission loss coefficient, R^2 value, and estimated level at 10 meters. These data, including distances to the Level A threshold for each hearing group, are summarized in Table 6-2.

Table 6-2. Summary of weighted transmission loss calculations for 36-inch temporary template piles installed with vibratory hammer

Pile ID	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 199 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 198 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 173 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 201 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 219 dB
MD5-A	15.0[a]	--	169	<1 m	15.0[a]	--	149	<1 m	15.0[a]	--	146	<1 m	15.0[a]	--	156	<1 m	15.0[a]	--	157	<1 m
MD5-B	15.0[a]	--	165	<1 m	15.0[a]	--	148	<1 m	15.0[a]	--	145	<1 m	15.0[a]	--	157	<1 m	15.0[a]	--	157	<1 m
MD5-D	15.0[a]	--	165	<1 m	15.0[a]	--	144	<1 m	15.0[a]	--	142	<1 m	15.0[a]	--	150	<1 m	15.0[a]	--	152	<1 m
MD5-C	15.0[a]	--	166	<1 m	15.0[a]	--	149	<1 m	15.0[a]	--	147	<1 m	15.0[a]	--	155	<1 m	15.0[a]	--	156	<1 m
MD6-A	15.0[a]	--	173	<1 m	15.0[a]	--	152	<1 m	15.0[a]	--	149	<1 m	15.0[a]	--	161	<1 m	15.0[a]	--	161	<1 m
MD6-B	15.0[a]	--	148	<1 m	15.0[a]	--	123	<1 m	15.0[a]	--	118	<1 m	15.0[a]	--	141	<1 m	15.0[a]	--	140	<1 m
MD6-D	15.0[a]	--	166	<1 m	15.0[a]	--	130	<1 m	15.0[a]	--	124	<1 m	15.0[a]	--	149	<1 m	15.0[a]	--	151	<1 m
MD6-C	10.8	0.9932	164	<1 m	9.2	0.9762	149	<1 m	8.4	0.9727	146	<1 m	12	0.9853	157	<1 m	11.5	0.9892	157	<1 m
MD3-D	14.5	0.9883	183	<1 m	18	0.978	167	<1 m	17.5	0.9663	163	3 m	17.8	0.9842	180	<1 m	17.3	0.984	179	<1 m
MD3-C	15.0[a]	--	187	2 m	15.0[a]	--	167	<1 m	15.0[a]	--	163	2 m	15.0[a]	--	180	<1 m	15.0[a]	--	180	<1 m
MD3-A	10.3	0.9847	177	<1 m	11.8	0.9558	152	<1 m	11.5	0.9134	147	<1 m	11.7	0.9861	170	<1 m	11.5	0.9861	170	<1 m
MD3-B	15.0[a]	--	173	<1 m	15.0[a]	--	153	<1 m	15.0[a]	--	151	<1 m	15.0[a]	--	159	<1 m	15.0[a]	--	160	<1 m
MD2-C	16.4	0.9975	187	2 m	18.2	0.9931	166	<1 m	16.1	0.9774	158	1 m	20.7	0.9999	186	2 m	20.1	0.9999	184	<1 m
MD2-D	15.0[a]	--	186	1 m	15.0[a]	--	162	<1 m	15.0[a]	--	156	1 m	15.0[a]	--	180	<1 m	15.0[a]	--	180	<1 m
Mean	14.43	0.9909	172	1 m	14.8	0.9757	151	<1 m	14.5	0.9575	147	1 m	15.2	0.9888	163	<1 m	15	0.9898	163	<1 m

[a] Estimated using a standard 15Log drop-off from the filtered 10-meter measurement.

Note: All data calculated between 20 and 20,000 Hz. dB = decibels; m = meters; R^2 = coefficient of determination; TL = transmission loss.

6.2 144-inch Vibratory Pile Driving Propagation and Threshold Distances

6.2.1 Unweighted Transmission Loss and Distances to the Level B Threshold

Two 144-inch piles were installed with a bubble curtain during May 2021, with about 1 minute of driving time. Both piles were driven using an APE 600 Quad Beam vibratory hammer. The vibratory driver did not properly attach to pile MD5. When activated, the hammer created a loud shaking and not a vibratory driving sound because the hammer was not attached to the pile correctly. Attempts were made to properly engage the driver and resolve the issue but were unsuccessful. Finally, the attempt to drive the pile was abandoned. The sounds reported here are from shaking the pile and are much louder than vibratory driving. The data points and trendlines for each individual pile are plotted on Figure 6-1. Table 6-3 summarizes the transmission loss coefficients, the coefficients of determination (R^2) for the trendlines, the estimated RMS levels at 10 meters, and the distance to the Level B threshold of 122.2 dB for individual piles.

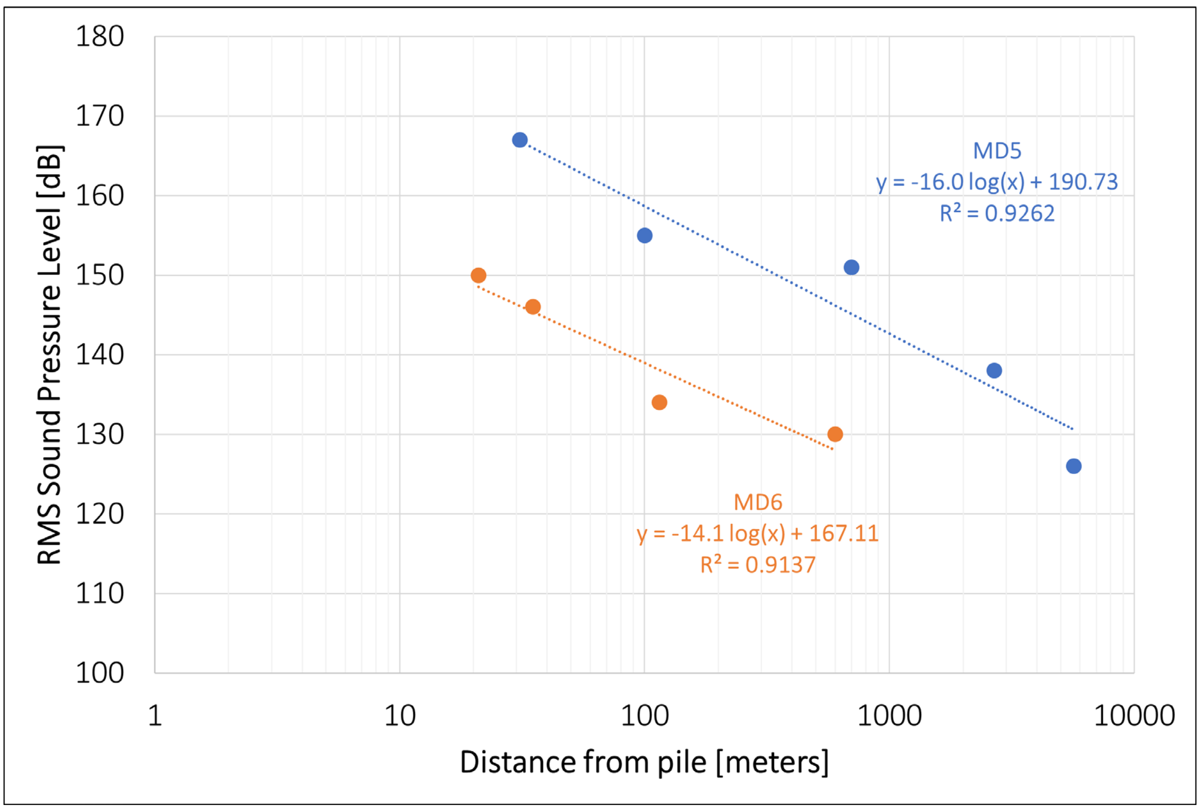

Figure 6-2. Data points and trendlines for all 144-inch piles installed with vibratory hammer

Table 6-3. Summary of unweighted transmission loss calculations for 144-inch piles installed with vibratory hammer (MD6) and an atypical shaking event (MD5)

Pile ID	Date	Duration of Drive	TL Coefficient	R^2 Value	Computed RMS Level at 10 m	Distance to Level B Threshold (122.2 dB)
MD5	5/26/2021	1 min	16.0	0.9262	175	19.7 km
MD6	5/29/2021	1.1 min	14.1	0.9137	153	1.5 km

Note: dB = decibels; m = meters; min = minute(s); R^2 = coefficient of determination; RMS = root mean square; TL = transmission loss.

6.2.2 Marine Mammal Weighting Transmission Loss and Distances to the Level A Thresholds

The marine mammal weightings were applied to the unweighted frequency spectra from Chapter 5, and the overall weighted levels for each marine mammal weighting category, between 20 and 20,000 Hz, were used to determine the transmission loss coefficient, R^2 value, and estimated level at 10 meters. These data, including distances to the Level A threshold for each hearing group, are summarized in Table 6-4 for vibratory installation of 144-inch piles.

Table 6-4. Summary of weighted transmission loss calculations for 144-inch piles installed with vibratory hammer (MD6) and an atypical shaking event (MD5)

Pile ID	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 183 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 185 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 155 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 203 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 185 dB
MD5	16.1	0.9296	188	2 m	12.1	0.9849	147	<1 m	10	0.9598	139	<1 m	16.9	0.9404	172	<1 m	16.4	0.9323	174	<1 m
MD6	15.7	0.9464	165	<1 m	12.5	0.6647	143	<1 m	12.2	0.619	141	<1 m	16	0.8821	153	<1 m	15.7	0.8903	154	<1 m

Note: All data calculated between 20 and 20,000 Hz. Coef. = coefficient; dB = decibels; R^2 = coefficient of determination; RMS = root mean square; TL = transmission loss.

6.3 144-inch Impact Pile Driving Propagation and Threshold Distances

6.3.1 Unweighted Transmission Loss and Distances to the Level B Threshold

Two attenuated 144-inch piles were installed using an IHC S-800 impact hammer, with driving times averaging 2 hours. Table 6-5 summarizes the transmission loss coefficients, the coefficients of determination (R^2) for the trendlines, the estimated RMS levels at 10 meters, and the distances to the Level B threshold of 160 dB for the individual attenuated piles. Additionally, Table 6-6 and Table 6-7 summarize the transmission loss coefficients, R^2 values, and estimated levels at 10 meters for peak and single-strike SELs, respectively.

Figure 6-3 shows the RMS data points and trendlines for each individual pile impacted, while Figure 6-4 and Figure 6-5 show the corresponding peak and single-strike SEL data points and trendlines for impact pile driving, respectively. Note that the sound fall-off rate (TL) is heavily influenced by the data points from the 6-km position. The 6-km position lies along a different transect that is south-southwest, while the other points at approximately 700 and 2,800 meters are to the west-northwest direction. The relative depth along the transect to 6 km is shallower and has a higher rate of sound attenuation.

Table 6-5. Summary of unweighted transmission loss calculations for all 144-inch attenuated piles during impact driving – RMS90% levels

Pile ID	Date	Total No. of Strikes	TL Coefficient	R^2 Value	Computed RMS Level at 10 m	Distance to Level B Threshold (160 dB)
MD5	5/27/2021	4,435	18.8	0.8153	207	3.3 km
MD6	5/29/2021	3,838	20.4	0.8127	208	2.1 km
Mean:		4,137	19.6	0.814	208	2.7 km
Regression Using All Points:			19.6	0.8088	207	2.6 km

Note: dB = decibels; m = meters; R^2 = coefficient of determination; RMS = root mean square; TL = transmission loss.

Table 6-6. Summary of unweighted transmission loss calculations for all 144-inch attenuated piles during impact driving – peak pressures

Pile ID	Date	Total No. of Strikes	TL Coefficient	R^2 Value	Computed Peak Level at 10 m	Distance to PTS Peak Threshold (202 dB)[a]
MD5	5/27/2021	4,435	19.4	0.8388	219	80 m
MD6	5/29/2021	3,838	20.6	0.8138	219	67 m
Mean:		4,137	20	0.8263	219	74 m
Regression Using All Points:			20.1	0.8176	219	73 m

[a]Peak pressure threshold for onset of PTS high-frequency cetaceans of 202 dB. Threshold is higher (218 to 232 dB for other hearing groups).

Note: dB = decibels; m = meters; R^2 = coefficient of determination; PTS = permanent threshold shift; RMS = root mean square; TL = transmission loss.

Table 6-7. Summary of unweighted transmission loss calculations for all 144-inch attenuated piles during impact driving – SEL levels

Pile ID	Date	Total No. of Strikes (Acoustical Pulses)	TL Coefficient	R^2 Value	Computed SEL Level at 10 m
MD5	5/27/2021	4,435	17.7	0.8480	194
MD6	5/29/2021	3,838	18.9	0.8108	193
Mean:		4,137	19.2	0.8079	194
Regression Using All Points:			18.3	0.8201	193

Note: m = meters; R^2 = coefficient of determination; SEL = sound exposure level; TL = transmission loss.

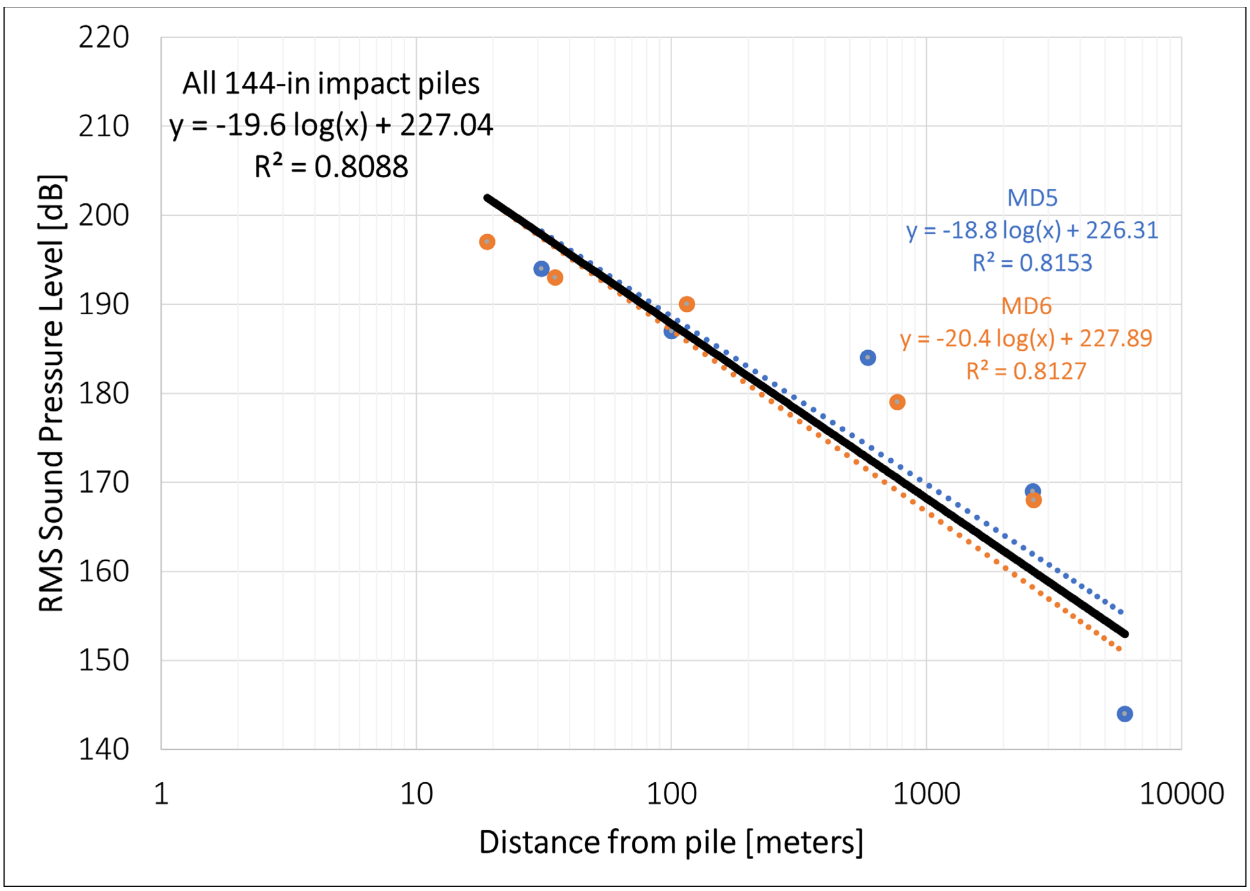

Figure 6-3. RMS90% data points and trendlines for all 144-inch piles installed with impact hammer

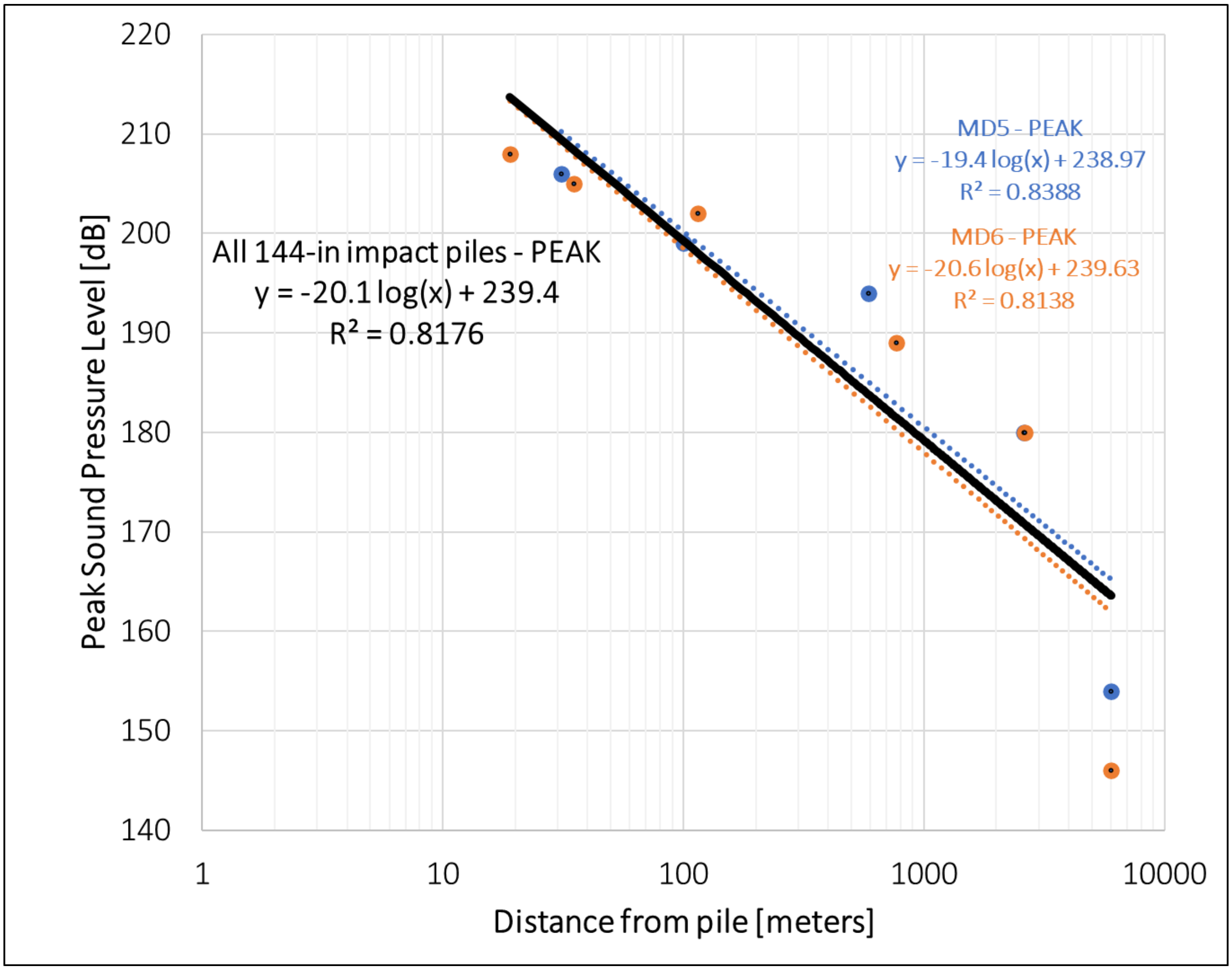

Figure 6-4. Peak pressure data points and trendlines for all 144-inch piles installed with impact hammer

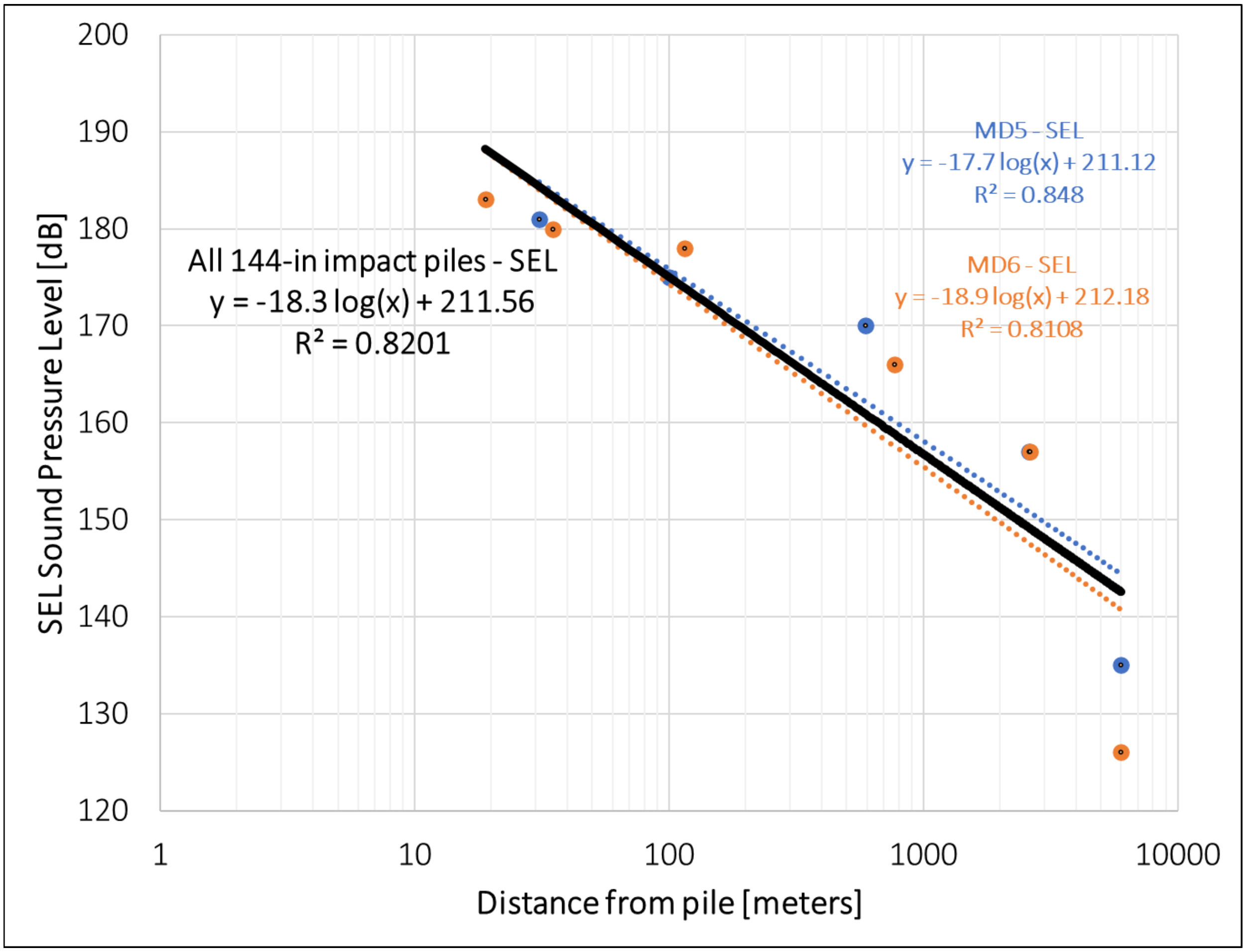

Figure 6-5. SEL data points and trendlines for all 144-inch piles installed with impact hammer

6.3.2 Marine Mammal Weighting Transmission Loss and Distances to the Level A Thresholds

The marine mammal weightings were applied to the unweighted frequency spectra from Chapter 5, and the overall weighted levels for each marine mammal weighting category, between 20 and 20,000 Hz, were used to determine the transmission loss coefficient, R^2 value, and estimated level at 10 meters. These data, including distances to the Level A threshold for each functional hearing group, are summarized in Table 6-8 for the 144-inch piles.

Table 6-8. Summary of weighted transmission loss calculations for 144-inch piles installed with impact hammer

Pile ID	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 183 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 185 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 155 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 203 dB	TL Coef.	R^2 Value	Comp. Level at 10 m	Dist. to 185 dB
MD5	19.3	0.783	233	3,698 m	16.8	0.768	195	40 m	15.2	0.729	189	1,663 m	20.2	0.788	218	56 m	19.7	0.783	219	560 m
MD6	16.8	0.723	228	5,000 m	16.3	0.843	192	28 m	15.5	0.883	185	912 m	17.2	0.734	214	46 m	17	0.731	216	645 m
Mean	18.05	0.753	231	4,349 m	16.6	0.805	194	34 m	15.4	0.806	187	1,288 m	18.7	0.761	216	51 m	18.4	0.757	218	603 m

Note: All data calculated between 20 and 20,000 Hz. See Table 6-6 for distances to peak thresholds. Coef. = coefficient; dB = decibels; m = meters; R^2 = coefficient of determination; TL = transmission loss.

6.4 General Discussion of Sound Levels and Propagation

In general terms, underwater pile driving noise is affected by the type of installation method (e.g., vibratory or impact), the pile diameter, the type of sound attenuation employed and its effectiveness, the depth of the water, and the composition of the sediment into which the pile is being driven. In this discussion, the near-source sound levels, rates of sound transmission, and distances to the various sound thresholds are described. The characteristics of the sound affect the sound transmissions, where typically low-frequency sounds attenuate at a lower rate than higher-frequency sounds. For impact sounds, there will be variability in pulsed-RMS measurements since the RMS level is a function of the pulse duration (in seconds). The characteristics of the sound emanating from the pile along with the contribution of sounds from the substrate can substantially vary the pulse duration. Longer-duration pulses can result in lower sound levels, even at similar energy levels (i.e., SEL). This discussion is based on pile size/type, installation method, attenuation effectiveness, and effects of water depth.

It is important to note that, in some cases, the computed distances to Level B thresholds extend well beyond the measurements' range of 6 km. In some cases, these distances extend well beyond the range where land or very shallow water would limit or prevent sound propagation.

Distances to Level B thresholds were computed three ways: (1) the regression coefficients for each pile driving event were computed individually, and then the average transmission loss and source levels were applied; (2) the regression coefficients for all data points from all pile driving events were computed; and (3) only the far-field data points (i.e., beyond 100 meters) were used to compute the regression coefficients (including source level), recognizing that the falloff rate is not constant over distance. Level A thresholds were computed similarly, except that the method using the far-field data only was not used because distance to this threshold was within the measurement range.

6.5 Impact Driving RMS Pulse Duration

The RMS SPL is computed across the duration of the pulse where 90 percent of the acoustical energy occurs. This is a transient value, as pile strike pulse durations vary from one strike to another. Typically, pulse duration lengthens as the sounds propagate farther from the source. This relationship can be observed as shown on Figure 6-6. Assuming constant energy, a shorter pulse results in a higher RMS SPL. Pulse duration and sound level become more variable with greater distance.

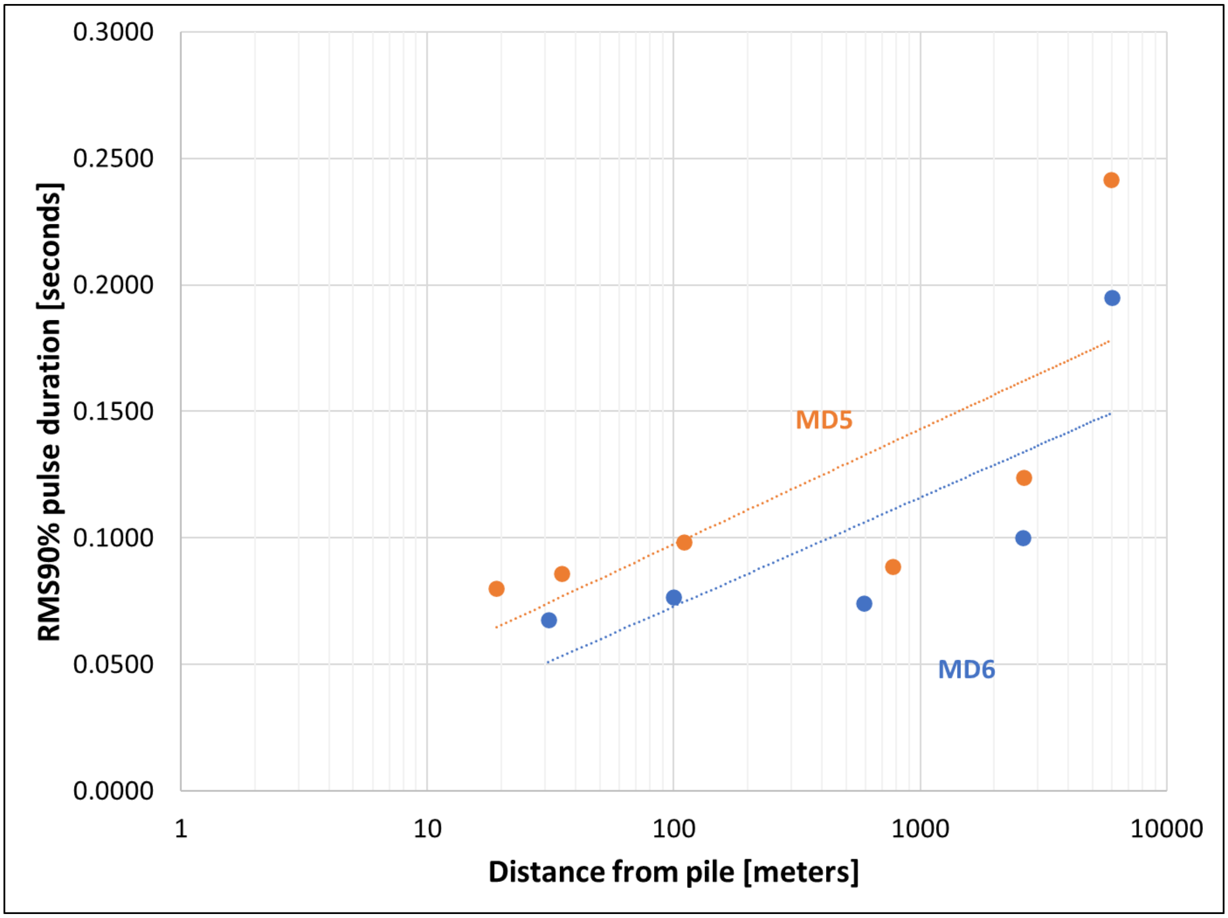

Figure 6-6. Pulse duration in seconds for RMS sound pressure level computation plotted by distance

6.6 Flow Noise Effects

Conducting underwater sound measurements in Knik Arm is challenging due to the high-velocity currents. Strong currents cause flow effects that are an artefact of the measurement process itself, with water moving against the hydrophone and creating a source of noise that is not naturally present in the environment. Water flowing across the hydrophone is one effect and so is movement of the entire hydrophone system. Use of a flow shield around the hydrophone reduced but did not eliminate this effect, which resulted in elevated low-frequency sound, with greatest effects below 50 Hz.

Noise from current flows affecting measurements at distant positions is present most of the time in datasets from this study. This noise could affect measured piling sounds if the measured amplitude level is within 10 dB of the background sound. To control this effect, measured background sound levels were logarithmically subtracted from the measured levels. This "flow noise" effect was most evident mainly at measurement distances at and beyond 600 meters from the piles, as can be seen by the spectrograms in Chapter 5. Spectrograms from measurements made at about 600 meters from the piles on May 27, 2021, are shown as an example on Figure 6-7 (for piles MD2-D and MD2-C), which shows high levels at about 30 Hz throughout the measurement duration. It is important to note that the fundamental pile driving frequency is also around the same frequency range as this flow noise range. Analyzing these data with a higher cutoff frequency when these low-frequency sounds are present would eliminate most of the flow noise but would also eliminate sound content from the piling activity.

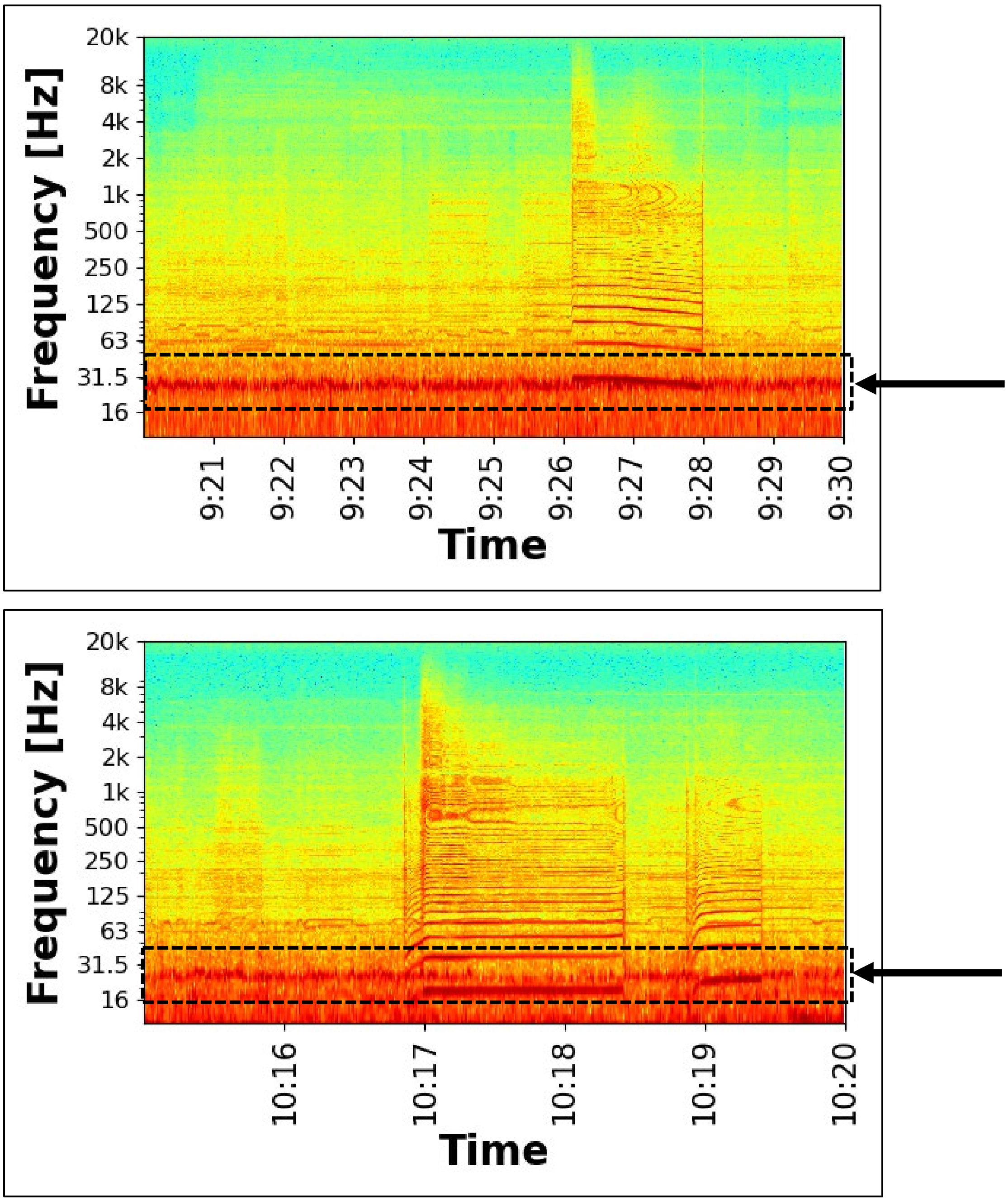

Figure 6-7. Spectrograms for MD2-C (top) and MD2-D (bottom) showing the high ambient levels at 30 Hz, demonstrating flow noise

In addition, flow noise affected mainly sound levels below approximately 20 Hz. Flow noise only increases sound levels, especially at distant positions where measured levels are quieter. Quieter piling events are possibly biased toward louder reported levels because of the influence of this background noise.

This analysis anticipated flow noise and used a cutoff frequency of 20 Hz (1/3-octave band center), since piling sounds are typically above this frequency band, and most background sound due to flow noise is at or below that frequency. Analyzing these data with a higher cutoff frequency when these low-frequency sounds are present would eliminate sound content from the piling activity. Table 6-9 provides a summary of the sound levels and transmission losses for vibratory pile installation of 36-inch piles when the higher frequency cutoffs of 50 and 100 Hz are applied. These cutoffs were applied only to pile measurements made near the pile and at the distant positions in the Knik Arm. In general, the higher frequency cutoffs result in higher attenuation rates (i.e., increased transmission losses) and lower sound levels. An ambient level of 122.2 dB was used, based on broadband sound measurements. That sound environment was likely influenced most by very low-frequency sound. A lower Level B threshold of 120 dB should be applied when comparing sound with a higher low-frequency cutoff (i.e., 50 and 100 Hz).

A similar analysis was conducted for impact pile driving. The elimination of sound content for frequencies below 50 and 100 Hz made little or no difference in the measured sounds caused by impact driving. This was expected, as the impact pile driving produced tonal sounds greater than 100 Hz with maximum sound energy in the 200- to 500-Hz 1/3-octave band frequencies.

Table 6-9. Comparison of levels using different low-frequency cutoffs for attenuated vibratory pile installation

Pile ID	Distance from Pile (m)	20 to 20 kHz	50 to 20 kHz	100 to 20 kHz
MD6-C	11	154	142	139
	32	149	138	135
	2640	120	116	115
	TL (Log10[distance])	14.5	11.1	10.2
	RMS 10 m level	155	143	139
	Distance to 122.2 dB	1.9 km	0.7 km	0.5 km
	Distance to 120 dB	N/A	1.0 km	0.8 km
MD3-D	29	156	155	154
	700	138	133	132
	2,670	131	130	129
	TL (Log10[distance])	13.5	13.3	13.3
	RMS 10 m level	161	161	160
	Distance to 122.2 dB	7.6 km	8.5 km	7.1 km
	Distance to 120 dB	N/A	12.4 km	10.4 km
MD3-A	11	160	158	156
	30	151	150	148
	660	140	135	133
	TL (Log10[distance])	10.5	12.5	12.5
	RMS 10 m level	159	157	155
	Distance to 122.2 dB	31.9 km	6.5 km	4.5 km
	Distance to 120 dB	N/A	9.8 km	6.8 km
MD2-C	72	151	150	149
	575	142	139	137
	2,650	130	127	125
	TL (Log10[distance])	13.2	14.5	15.2
	RMS 10 m level	163	163	162
	Distance to 122.2 dB	12.8 km	5.9 km	4.1 km
	Distance to 120 dB	N/A	8.4 km	5.8 km
All 36-inch Piles (Mean)	TL (Log10[distance])	12.9	12.9	12.8
	RMS 10 m level	158	156	154
	Distance to 122.2 dB	6.0 km	5.9 km	4.1 km
	Distance to 120 dB	N/A	7.9 km	6 km
All 36-inch Piles (Regression Using All Points)	TL (Log10[distance])	12.2	11.6	11.4
	R^2 value	0.8707	0.7187	0.683
	RMS 10 m level	160	155	153
	Distance to 122.2 dB	11.8 km	6.5 km	5 km
	Distance to 120 dB	N/A	10 km	7.8 km

Note: dB = decibels; kHz = kilohertz; km = kilometers; m = meters; R^2 = coefficient of determination; RMS = root mean square; TL = transmission loss.

6.7 Air Bubble Curtain Performance

The multi-ring air bubble curtain was in operation for all piling events measured. Since there was no air bubble curtain on-and-off operation, it is not possible to measure the effectiveness of the system in reducing sound levels. Indications of air bubble curtain performance in reducing sound is made by comparing measured sound levels against unattenuated levels predicted in the IHA.

6.7.1 Thirty-six-inch Vibratory Pile Driving

Overall measurements for 36-inch-diameter template piles installed with a vibratory driver found RMS sound levels to be 158 dB at 10 meters from the pile. Unattenuated, the IHA application predicted sound levels of 166 dB at 10 meters from the pile, indicating a reduction of possibly 8 dB at 10 meters from the pile. In comparison, hydroacoustic measurements for Phase 1 of the PCT in 2020 indicated an overall level of 161 dB. The 2020 measurements had a higher 10-meter sound level but a lower TL of 14.3 versus a TL of 11.3. Furthermore, in 2020, a confined bubble curtain system was used, but in 2021, an unconfined bubble curtain system was used.

Many of the measurements made for these 36-inch-diameter piles were conducted at 10 to 20 meters and at about 30 meters. It is noted that these levels at 30 meters were only about 3 to 4 dB lower than at 10 to 20 meters and in one case the 30-meter position levels were higher than the 10-meter levels. This is an indication that there was little to no sound transmission loss near the pile and air bubble curtain. When only evaluating sounds in the very far-field (i.e., 100 meters out to 2,800 meters), the TL computed was much greater at 19.0. Sounds that propagate westward into deep water tend to fall off at a slow rate near the pile and then at a much higher rate far away from the pile. The TL rate does not appear to be Log linear.

The 2020 hydroacoustic assessment found that higher TLs typically occurred when near-source sound levels (i.e., at 10 meters) were higher. This was most clearly illustrated when a 48-inch-diameter pile (Pile A-1) was vibrated without an attenuation system. That pile had levels 8 dB louder than piles of that size with an air bubble attenuation system. The TL of 18. 2 was much higher compared to a TL of 13.0 for attenuated conditions. It was also found for all cases that the resulting sound levels in the far field are comprised mostly of very low frequency sound content. These sounds are most difficult to control using air bubble systems for sound attenuation.

Overall, the acoustic data indicate that the air bubble curtain is effective near the pile but has less effect far from the pile where much of the higher frequency sound content is attenuated due to transmission loss through ground and water with distance.

6.7.2 One-hundred-forty-four-inch Vibratory Pile Driving

As discussed previously, there were only short measurements of piling using a vibratory driver when the air bubble curtain system was operating. One event was atypical and not representative of vibratory driving. Measured sound levels from typical vibratory driving with the air bubble curtain were much lower than anticipated. Sound pressure levels were 153 dB at 10 meters from the pile. The IHA application predicted 171 dB at 10 meters. The lower measured sound level is likely a combination of air bubble curtain performance and lower sound generation by the activity.

6.7.3 One-hundred-forty-four-inch Impact Pile Driving

Impact driving produced median sound levels per strike of 219 dB peak, 207 dB RMS (pulse), and 193 dB SEL. These levels were about 5 dB lower than anticipated unattenuated levels predicted in the IHA application. Impact pile driving produced measurable sound well above background over the frequency range of about

12.5 to 2,500 Hz throughout at all measurement positions out to 6 km, with 100 to 200 Hz being the dominant frequency range. Since the 144-inch-diameter pile sound levels were developed from theoretical data using sounds from other piles sizes, it is not possible to make an accurate comparison to unattenuated conditions.

7 Personnel

This hydroacoustic monitoring effort was conducted by Illingworth & Rodkin, Inc., staff with assistance and direction provided by HDR. Vessel support was provided by *eTrac*, which included the deployment and retrieval of the acoustic moorings each day in challenging marine conditions due to strong tidal currents. The field monitoring activities were carried out by James Reyff, with support from Brett Carrothers, Leslie Curran, and Suzann Speckman. Numerous other HDR personnel provided support during this field effort, including Kevin Doyle and Anna Kohl with project management; Brian Hessert, Meshkat Mirzaei, and Sim Brubaker with field support; and Tina Adair with document finalization. Adwait Ambaskar, assisted by James Reyff, led the data analysis effort and drafting of the report. The final report was reviewed by Carrie Janello. Overall support for this effort was made possible by the Port of Alaska.

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9 Glossary

Ambient sound – Normal background noise in the environment that has no distinguishable sources.

Ambient sound level – The background sound pressure level at a given location, normally specified as a reference level to study a new intrusive sound source.

Amplitude – The maximum deviation between the sound pressure and the ambient pressure.

Background level – Similar to ambient sound level with the exception that it is a composite of all sound measured during the construction period minus the pile removal.

Continuous sound –Sound whose fluctuating sound pressure level remains above ambient sound during the event period (e.g., vibratory pile driving). In this report, non-impulsive sounds are considered continuous sounds.

Decibel (dB) – A customary scale most commonly used for reporting levels of sound. A difference of 10 dB corresponds to a factor of 10 in sound power. A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for water is 1 microPascal, and for air it is 20 microPascals (the threshold of healthy human auditory sensitivity).

Fast, Slow, and Impulse – Most sound level meters have two conventional time weightings, F=Fast and S = Slow, with time constants of 125 milliseconds (ms) and 1,000 ms, respectively. Some also have I = Impulse time weighting, which is a quasi-peak detection characteristic with rapid rise time (35 ms) and a much slower 1.5-second decay.

- F = 125 ms up and down
- S = 1 second up and down
- I = 35 ms while the signal level is increasing or 1,500 ms while the signal level is decreasing

Frequency – The number of complete pressure fluctuations per second above and below ambient pressure, measured in cycles per second (Hertz [Hz]). Normal human hearing is between 20 and 20,000 Hz. Infrasonic sounds are below 20 Hz and ultrasonic sounds are above 20,000 Hz.

Frequency spectrum – The distribution of frequencies that comprise a sound.

Hertz (Hz) – The units of frequency where 1 Hz equals 1 cycle per second.

Impulsive sound - Transient sounds that are brief (less than 1 second) that are characterized by high peak sound pressure with rapid rise time and rapid decay. These sounds can occur in prepetition (e.g., pile driving) or a single event (e.g., explosion). There is no definition of the repetitive rate that defines sound as impulsive or continuous.

Kilohertz (kHz) – 1,000 Hz.

L_{eq} – *Equivalent Average Sound Pressure Level (or Energy-Averaged Sound Level).* The decibel level of a constant noise source that would have the same total acoustical energy over the same time interval as the actual time-varying noise condition being measured or estimated. L_{eq} values must be associated with an explicit or implicit averaging time in order to have practical meaning.

MicroPascal (µPa) – The Pascal (symbol Pa) is the SI (International System of Units) unit of pressure. It is equivalent to 1 Newton per square meter. There are 1,000,000 microPascals in 1 Pascal.

Peak sound pressure level (L_{pk}) – The largest absolute value of the instantaneous sound pressure. This pressure is expressed in decibels (referenced to a pressure of 1 µPa for water and 20 µPa for air) or in units of pressure, such as µPa or pounds per square Inch.

Root mean square (RMS) sound pressure level – Decibel measure of the square root of mean square (RMS) pressure. For impulses, the average of the squared pressures over time that comprise that portion of the waveform containing 90 percent of the sound energy of the impulse. To define continuous sources in this SSV, a time constant of 1 second was used over the duration of activities.

SLM – Sound level meter. The Larson Davis model 831 and model 831c SLMs were used.

Sound – Small disturbances in a fluid from ambient conditions through which energy is transferred away from a source by progressive fluctuations of pressure (or sound waves).

Sound exposure – The integral over all time of the square of the sound pressure of a transient waveform.

Sound exposure level (SEL) – The time integral of frequency-weighted squared instantaneous sound pressures. Proportionally equivalent to the time integral of the pressure squared. Sound energy associated with a pile driving pulse, or series of pulses, is characterized by the SEL. SEL is the constant sound level in 1 second, which has the same amount of acoustic energy as the original time-varying sound (i.e., the total energy of an event). SEL is calculated by summing the cumulative pressure squared over the time of the event ($1 \mu Pa^2$-sec).

Sound pressure level (SPL) – An expression of the sound pressure using the decibel (dB) scale and the standard reference pressures of 1 µPa for water, and 20 µPa for air and other gases. Sound pressure is the sound force per unit area, usually expressed in microPascals (or microNewtons per square meter), where 1 Pascal is the pressure resulting from a force of 1 Newton exerted over an area of 1 square meter. The SPL is expressed in dB as 20 times the logarithm to the base 10 of the ratio between the pressure exerted by the sound to a reference sound pressure. SPL is the quantity directly measured by an SLM.

Weighting factor adjustment (WFA) – Adjustments to sound levels based on marine mammal auditory weighting functions that focus on a single frequency. These adjustments are applied to the following marine mammal hearing groups: low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, Phocid pinnipeds (underwater), and Otariid pinnipeds (underwater).

Appendix A
Summary Measured Data Tables for Vibratory Driving of 36-inch Piles

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Table A-1. Daily data summary for vibratory pile driving activities on May 17, 2021

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
					Pile	Hydro-phone	Max	Median	Mean		Max	Median	Mean
14:31 to 14:38	MD5-A	APE 600 Vibratory	5.0 minutes	11m	14m	14 m	184	166	164	182	165	156	155
				31m		10 m	183	161	161	178	163	152	150
15:29 to 15:37	MD5-B		5.9 minutes	12m	13m	13 m	172	163	163	179	160	153	151
				30m		9 m	166	159	157	176	155	150	147

Table A-2. Daily data summary for vibratory pile driving activities on May 18, 2021

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
					Pile	Hydro-phone	Max	Median	Mean		Max	Median	Mean
14:53 to 15:00	MD5-D	APE 600 Vibratory	5.8 minutes	10	15	15 m	171	159	159	175	156	149	149
				30		11 m	171	160	160	177	157	152	150
15:56 to 16:06	MD5-C		9.2 minutes	19	13	13 m	168	152	152	171	155	142	141
				38		9 m	174	155	156	176	157	146	145

Table A-3. Daily data summary for vibratory pile driving activities on May 19, 2021

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
					Pile	Hydro-phone	Max	Median	Mean		Max	Median	Mean
11:24 to 11:32	MD6-A	APE 600 Vibratory	6.1 minutes	10	14	14 m	184	169	170	186	166	159	159
				25		10 m	172	164	164	178	158	155	154
13:00 to 13:08	MD6-B		4.9 minutes	10	14	14 m	183	168	168	185	165	158	157
				29		13 m	183	164	165	181	162	155	154

Table A-4. Daily data summary for vibratory pile driving activities on May 20, 2021

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
					Pile	Hydro-phone	Max	Median	Mean		Max	Median	Mean
8:23 to 8:31	MD6-D	APE 600 Vibratory	6.3 minutes	10	10	10 m	172	161	160	180	160	154	152
				30		10 m	174	158	157	177	157	150	148
9:24 to 9:33	MD6-C		7.2 minutes	11	10	10 m	174	163	163	184	162	155	154
				32		10 m	176	156	155	178	151	148	146
				2,640		11 m	146	132	132	146	131	121	121

Table A-5. Daily data summary for vibratory pile driving activities on May 25, 2021

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
					Pile	Hydro-phone	Max	Median	Mean		Max	Median	Mean
7:43 to 7:52; 8:59 to 9:00	MD3-D	APE 600 Vibratory	7.6 minutes	29	16	16	186	170	170	184	165	155	156
				700		30	185	148	148	160	148	135	135
				2,670		15	182	143	145	165	154	129	130
8:39 to 8:54	MD3-C		9.0 minutes	27	15	15	192	172	169	187	167	160	157
				700		30	186	154	155	169	158	142	144
				2,670		15	163	149	150	167	140	134	137

Table A-6. Daily data summary for vibratory pile driving activities on May 26, 2021

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
					Pile	Hydro-phone	Max	Median	Mean		Max	Median	Mean
8:44 to 8:55; 9:57 to 9:58	MD3-A	APE 600 Vibratory	9.1 minutes	11	17	17	204	171	172	191	183	160	160
				30		17	191	164	165	181	169	151	151
				660		30	170	150	151	168	152	140	141
9:43 to 9:52	MD3-B		7.7 minutes	11	15	15	173	166	164	183	161	157	154
				660		30	150	145	144	165	142	137	137

Table A-7. Daily data summary for vibratory pile driving activities on May 27, 2021

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
					Pile	Hydro-phone	Max	Median	Mean		Max	Median	Mean
9:24 to 9:28; 10:11 to 10:12	MD2-C	APE 600 Vibratory	4.6 minutes	72	18	17	178	162	163	174	160	151	152
				575		29	169	154	155	166	150	142	143
				2,650		14	181	142	144	162	156	130	131
10:17 to 10:19	MD2-D		2.0 minutes	72	18	15	181	169	169	179	164	153	154
				575		29	165	149	150	162	148	137	138

Appendix B
Summary Measured Data Tables for Vibratory Driving of 144-inch Piles

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Table B-1. Daily data summary for vibratory pile driving activities on May 26, 2021

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
					Pile	Hydro-phone	Max	Median	Mean		Max	Median	Mean
15:46; 15:49; 15:50; 15:57; 16:07; 16:12 to 16:13; 16:14 to 16:15	MD5	APE 600 Vibratory	1.0 minute	31	10	17	186	180	179	186	173	167	166
				100		17	182	170	170	191	166	155	156
				700		30	174	164	165	171	159	151	151
				2700		17	161	151	152	158	147	138	139
				5700		20	162	139	139	146	134	126	127

Table B-2. Daily data summary for vibratory pile driving activities on May 29, 2021

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
					Pile	Hydro-phone	Max	Median	Mean		Max	Median	Mean
14:58 to 15:02	MD6	APE 600 Vibratory	1.1 minutes	21	9	7	171	159	159	169	160	150	150
				35		7	166	158	158	165	154	146	146
				115		7	156	144	144	154	145	134	134
				600		15	148	<139	<140	149	136	<129	<130
				2600		9	158	<137	<139	144	131	<123	<124
				6000		7	140	<131	<131	138	126	<118	<118

Appendix C
Summary Measured Data Tables for Impact Driving of 144-inch Piles

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Table C-1. Daily data summary for impact pile driving activities on May 27, 2021

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			cSEL	90% RMS (dB)			90% Pulse Duration (sec)		
					Pile	Hydro.	Max	Median	Mean	Max	Median	Mean		Max	Median	Mean	Max	Median	Mean
13:07 to 15:28	MD5	IHC S-800 Impact	4435 strikes	31	9	9	216	206	206	188	181	180	213	204	194	194	0.1939	0.0676	0.0686
				100		9	204	199	199	179	175	175	212	193	187	188	0.1117	0.0764	0.0753
				590		9	198	194	193	176	170	169	207	189	184	183	0.2022	0.0742	0.0731
				2,610		9	183	180	180	158	157	156	193	170	169	168	0.2727	0.1000	0.0965
				6,000		6	158	154	153	139	135	134	172	149	144	143	0.2876	0.1950	0.2002

Table C-2. Daily data summary for impact pile driving activities on May 29, 2021

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			cSEL	90% RMS (dB)			90% Pulse Duration (sec)		
					Pile	Hydro.	Max	Median	Mean	Max	Median	Mean		Max	Median	Mean	Max	Median	Mean
16:04 to 17:45	MD6	IHC S-800 Impact	3835 strikes	19	7	5	209	208	208	185	183	183	219	199	197	197	0.1537	0.0858	0.0856
				35		5	209	205	205	183	180	180	216	197	193	193	0.2104	0.0858	0.0856
				110		5	208	202	202	183	178	178	214	197	190	190	0.2056	0.0985	0.0987
				770		16.5	194	189	190	170	166	167	203	184	179	179	0.2089	0.0887	0.0866
				2,630		9.5	184	180	181	160	157	157	193	171	168	168	0.2104	0.1238	0.1253
				5.970		7.5	151	146	146	131	126	126	161	140	135	135	0.2801	0.2417	0.2413

Appendix D
Pile-Driving Records

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Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/17/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD5-A (SE)	**Structure Name:**	MD5
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-22.91
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	36.61	**Hammer Energy:**	-
Ending Water Depth (ft):	36.21	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	375	400	425	450	500	525	550

Vibratory Pile Driving Data

Pile Elev at Reference		Start	Stop	Comments
Start	**Stop**	**Time**	**Time**	
		2:16:16 PM		Pile in template
		2:27:35 PM		Hammer on pile
40.0	57.0	2:31:03 PM	2:33:54 PM	
57.0	84.0	2:34:33 PM	2:37:25 PM	
				`

Additional Comments: This pile is located Southeast of MD5

Total drive time (h:mm:ss): 0:06:22

Mudline elevation was taken from PCT 2020 Conditional Survey on 11/08/2020

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/17/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD5-B (SW)	**Structure Name:**	MD5
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-25.28
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	34.68	**Hammer Energy:**	-
Ending Water Depth (ft):	34.38	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	375	400	400	400	425	450	500

Vibratory Pile Driving Data

Pile Elev at Reference		**Start**	**Stop**	**Comments**
Start	**Stop**	**Time**	**Time**	
		3:27:33 PM		Hammer on pile
		3:29:43 PM	3:31:25 PM	
60.0	70.0	3:31:46 PM	3:33:21 PM	
70.0	83.0	3:33:47 PM	3:35:58 PM	
83.0	83.0	3:36:16 PM	3:37:06 PM	Vibed pile up and back down to get to correct tip elevation
				`

Additional Comments: This pile is located Southwest of MD5

Total drive time (h:mm:ss): 0:07:23

Mudline elevation was taken from PCT 2020 Conditional Survey on 11/08/2020

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/18/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD5-D (NE)	**Structure Name:**	MD5
Pile Length (ft):	~100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-25.28
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	41.18	**Hammer Energy:**	-
Ending Water Depth (ft):	40.58	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	400	400	450	450	475	500	525

Vibratory Pile Driving Data

Pile Elev at Reference		Start	Stop	Comments
Start	**Stop**	**Time**	**Time**	
		2:37:55 PM		Pile in template
		2:50:43 PM		Hammer on pile
		2:53:32 PM	2:54:36 PM	
		2:55:11 PM	2:56:40 PM	
		2:57:20 PM	3:01:23 PM	
				`

Additional Comments: This pile is located Northeast of MD5

Total drive time (h:mm:ss): 0:07:51

Mudline elevation was taken from PCT 2020 Conditional Survey on 11/08/2020

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/18/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD5-C (NW)	**Structure Name:**	MD5
Pile Length (ft):	~100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-25.78
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	37.38	**Hammer Energy:**	-
Ending Water Depth (ft):	36.68	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	400	400	400	400	400	450	500

Vibratory Pile Driving Data

Pile Elev at Reference		Start	Stop	Comments
Start	Stop	Time	Time	
		3:55:43 PM		Hammer on pile
		3:56:31 PM	3:57:43 PM	
		3:58:23 PM	3:59:53 PM	
		4:00:46 PM	4:07:18 PM	
				`

Additional Comments: This pile is located Northwest of MD5

Total drive time (h:mm:ss): 0:10:47

Mudline elevation was taken from PCT 2020 Conditional Survey on 11/08/2020

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/19/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD6-A (SE)	**Structure Name:**	MD6
Pile Length (ft):	~100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-31.88
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	Low	**Attenuated:**	Yes
Tidal Movement:	Flood	**Active # Rings:**	7
Start Water Depth (ft):	52.98	**Hammer Energy:**	-
Ending Water Depth (ft):	53.08	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	400	400	425	450	450	500	500

Vibratory Pile Driving Data

Pile Elev at Reference		**Start**	**Stop**	**Comments**
Start	**Stop**	**Time**	**Time**	
		11:11:01 AM		Pile in template
		11:19:49 AM		Hammer on pile
		11:26:12 AM	11:27:32 AM	
		11:28:12 AM	11:32:01 AM	
				`

Additional Comments: This pile is located Southeast of MD6

Total drive time (h:mm:ss)= 0:05:49

Mudline elevation was taken from PCT 2020 Conditional Survey on 11/08/2020

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/19/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD6-B (SW)	**Structure Name:**	MD6
Pile Length (ft):	~100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-31.88
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Slack	**Active # Rings:**	7
Start Water Depth (ft):	55.48	**Hammer Energy:**	-
Ending Water Depth (ft):	55.48	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	375	400	400	425	450	500	500

Vibratory Pile Driving Data

Pile Elev at Reference		Start Time	Stop Time	Comments
Start	Stop			
		12:58:00 PM		Hammer on pile
		1:00:00 PM	1:04:00 PM	
		1:05:00 PM	1:07:00 PM	
				`

Additional Comments: This pile is located Southwest of MD6

Total drive time (h:mm:ss): 0:07:00

Mudline elevation was taken from PCT 2020 Conditional Survey on 11/08/2020

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/20/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD6-D (NE)	**Structure Name:**	MD6
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-34.63
Reference:	Top of template	**Reference Elev. (ft):**	13

Environmental

Tidal Stage:	Low	**Attenuated:**	Yes
Tidal Movement:	Slack	**Active # Rings:**	7
Start Water Depth (ft):	43.33	**Hammer Energy:**	-
Ending Water Depth (ft):	43.23	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	300	350	400	400	420	500	500

Vibratory Pile Driving Data

Pile Elev at Reference		**Start**	**Stop**	**Comments**
Start	**Stop**	**Time**	**Time**	
		8:05:36 AM		Pile in template
		8:19:29 AM		Hammer on pile
		8:23:13 AM	8:25:32 AM	
		8:26:01 AM	8:29:11 AM	
		8:30:08 AM	8:31:05 AM	Had to raise pile and drive it to correct tip elevation
				`

Additional Comments: This pile is located Northeast of MD6

Total drive time (h:mm:ss): 0:07:52

Mudline elevation was taken from PCT 2020 Conditional Survey on 11/08/2020

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/20/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD6-C (NW)	**Structure Name:**	MD6
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-33.74
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	Low	**Attenuated:**	Yes
Tidal Movement:	Flood	**Active # Rings:**	7
Start Water Depth (ft):	42.84	**Hammer Energy:**	-
Ending Water Depth (ft):	43.04	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	400	400	400	400	400	450	500

Vibratory Pile Driving Data

Pile Elev at Reference Start	Pile Elev at Reference Stop	Start Time	Stop Time	Comments
		9:20:06 AM		Hammer on pile
		9:24:07 AM	9:24:56 AM	
		9:25:32 AM	9:27:41 AM	
		9:28:22 AM	9:30:00 AM	
		9:30:19 AM	9:33:12 AM	
				`

Additional Comments: This pile is located Northwest of MD6

Total drive time (h:mm:ss): 0:09:05

Mudline elevation was taken from PCT 2020 Conditional Survey on 11/08/2020

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/25/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD3-D (NE)	**Structure Name:**	MD3
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-14.39
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	45.59	**Hammer Energy:**	-
Ending Water Depth (ft):	43.89	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	400	400	450	500	500	500	550

Vibratory Pile Driving Data

Pile Elev at Reference		Start	Stop	Comments
Start	**Stop**	**Time**	**Time**	
		7:22:00 AM	7:24:00 AM	
		7:25:02 AM	7:26:00 AM	Picked up pile to move barge back in position
		7:34:11 AM	7:35:29 AM	
		7:36:19 AM	7:37:11 AM	stoppd to move the barge again
		7:43:14 AM	7:44:28 AM	
		7:45:13 AM	7:46:23 AM	
		7:46:50 AM	7:51:17 AM	stopped short due to template being at cut off elev
		8:59:11 AM	9:00:39 AM	vibed to grade after tide went down
				`

Additional Comments: This pile is located Northeast of MD3

Total drive time (h:mm:ss): 0:29:17

Mudline elevation was taken from PPM (eTrac) survey from 5/18/2021.

The bubble curtain was damaged while driving this pile.

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/25/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD3-C (NW)	**Structure Name:**	MD3
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-18.7
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	43.6	**Hammer Energy:**	-
Ending Water Depth (ft):	42.2	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	475	500	500	500	500	525	550

Vibratory Pile Driving Data

Pile Elev at Reference		Start	Stop	Comments
Start	**Stop**	**Time**	**Time**	
		8:27:12 AM		pile in template
		8:40:02 AM		hammer on pile
		8:44:31 AM	8:45:44 AM	
		8:46:58 AM	8:47:41 AM	
		8:49:04 AM	8:54:35 AM	
				`

Additional Comments:

Total drive time (h:mm:ss): 0:10:04

Mudline elevation was taken from PPM (eTrac) survey from 5/18/2021.

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/26/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD3-A (SE)	**Structure Name:**	MD3
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-18.22
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	47.52	**Hammer Energy:**	-
Ending Water Depth (ft):	46.82	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	425	475	475	500	500	500	550

Vibratory Pile Driving Data

Pile Elev at Reference		Start	Stop	Comments
Start	**Stop**	**Time**	**Time**	
		8:25:03 AM		pile in template
		8:40:05 AM		hammer on pile. Struggling due to strong currents
		8:44:35 AM	8:46:06 AM	
		8:46:52 AM	8:47:45 AM	
		8:47:51 AM	8:48:10 AM	
		8:48:26 AM	8:55:08 AM	stopped short due to template being in the way
		8:56:00 AM		hammer back on pile
		9:57:57 AM	9:58:34 AM	
				`

Additional Comments: this pile is located Southeast of MD3

Total drive time (h:mm:ss): 0:11:33

Mudline elevation was taken from PPM (eTrac) survey from 5/18/2021.

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/26/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD3-B (SW)	**Structure Name:**	MD3
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-17.69
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	41.19	**Hammer Energy:**	-
Ending Water Depth (ft):	40.29	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	475	500	500	500	520	525	525

Vibratory Pile Driving Data

Pile Elev at Reference		Start	Stop	Comments
Start	**Stop**	**Time**	**Time**	
		9:30:22 AM		pile in template
		9:39:37 AM		hammer on pile
		9:43:11 AM	9:45:16 AM	
		9:46:00 AM	9:47:53 AM	
		9:48:41 AM	9:52:42 AM	
				`

Additional Comments: This pile is located Southwest of MD3

Total drive time (h:mm:ss): 0:09:31

Mudline elevation was taken from PPM (eTrac) survey from 5/18/2021.

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/26/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	Super Kong
Pile Name:	MD5	**Structure Name:**	MD5
Pile Length (ft):	202' 4"	**Bent #:**	-
Pile Diameter (in):	144	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-159	**Mudline Elev (ft):**	-25.3
Reference:	-151.514	**Reference Elev. (ft):**	32

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	4
Start Water Depth (ft):	29.3	**Hammer Energy:**	-
Ending Water Depth (ft):	29.3	**Do bubbles fully encapsulate pile?**	No
		Approx. Max. Distance between Bubbles and Pile (ft):	~5

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	700	700	700	700			

Vibratory Pile Driving Data

Footmark at Reference		**Start**	**Stop**	**Comments**
Start	**Stop**	**Time**	**Time**	
		1:17:39 PM		Pile in template
		3:47:16 PM		Hammer on pile. Hammer is not clamping on pile
		3:54:42 PM		Pulling hammer off of pile
81.0	83.0	4:10:21 PM	4:13:21 PM	
83.0	84.0	4:15:47 PM	4:16:11 PM	
		4:17:57 PM		hammer off. Top of pile elev: 154.50'
				`

Additional Comments:

Total drive time (h:mm:ss): 0:05:50 Used about 42 seconds of actual vibratory time.

Mudline elevation was taken from PCT-2020 Post Survey performed on 11/04/2020.

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/27/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD2-C (NW)	**Structure Name:**	MD2
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-15.2
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	44.9	**Hammer Energy:**	-
Ending Water Depth (ft):	44.4	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	450	475	500	525	525	550	550

Vibratory Pile Driving Data

Pile Elev at Reference		**Start**	**Stop**	**Comments**
Start	**Stop**	**Time**	**Time**	
		9:12:00 AM		pile in template
		9:22:00 AM		hammer on pile
		9:24:00 AM	9:24:00 AM	
		9:25:00 AM	9:27:00 AM	
		10:19:00 AM	10:20:00 AM	
				`

Additional Comments:

Total drive time (h:mm:ss)= 0:04:00

Mudline elevation was taken from PPM (eTrac) survey from 5/18/2021.

Inspector Signature: Meshkat Mirzaei

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/27/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	300-6
Pile Name:	MD2-D (NE)	**Structure Name:**	MD2
Pile Length (ft):	100	**Bent #:**	-
Pile Diameter (in):	36	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-	**Mudline Elev (ft):**	-9.06
Reference:	Top of template	**Reference Elev. (ft):**	-

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	7
Start Water Depth (ft):	42.06	**Hammer Energy:**	-
Ending Water Depth (ft):	41.66	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~8

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	425	475	475	500	500	500	525

Vibratory Pile Driving Data

Pile Elev at Reference		**Start**	**Stop**	**Comments**
Start	**Stop**	**Time**	**Time**	
		8:26:00 AM		pile in tempalte
		8:32:00 AM		hammer on pile
		8:34:00 AM	8:36:00 AM	
		8:37:00 AM	8:37:30 AM	
		8:38:00 AM	8:40:00 AM	Had to stop due to template being too high
		10:11:00 AM	10:12:00 AM	
				`

Additional Comments:

Total drive time (h:mm:ss)= 0:07:00

Mudline elevation was taken from PPM (eTrac) survey from 5/18/2021.

Inspector Signature: Meshkat Mirzaei

Impact Pile Driving Log

Job Name:	PCT 2021	**Driving Date:**	5/27/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	IHC S-800
Pile Name:	MD-5	**Structure Name:**	MD-5
Pile Length:	202' 4"	**Mudline Elev:**	-25.3'
Pile Diameter:	144"	**Reference:**	top of template
Pile Type:	Plumb	**Reference Elev:**	32.0'
Final Tip Elev:	-159.5'		

Environmental

Tidal Stage:	High			**Attenuated:**	Yes
Tidal Movement:	Ebb			**Active # of Rings:**	start 4, end 3
Start Water Depth:	30.3'	**End Water Depth:**	20.9'	**Hammer Energy:**	-
Distance between Bubbles and Pile:	5'		**Do bubbles fully encapsulate pile?**		Yes
Compressor/ring #	1	2	3	4	
CFM Flow Rate:	700	700	700	700	

Footmark At Reference	Embedded Depth	Blows/ Foot	Footmark At Reference	Embedded Depth	Blows/ Foot
	1'	Embedment due to self weight and / or vibratory hammer		23'	Embedment due to self weight and / or vibratory hammer
	2'			24'	
	3'			25'	
	4'			26'	
	5'			27'	
	6'			28'	
	7'			29'	
	8'			30'	
	9'		90	31'	19
	10'		91	32'	26
	11'		92	33'	39
	12'		93	34'	32
	13'		94	35'	34
	14'		95	36'	33
	15'		96	37'	33
	16'		97	38'	32
	17'		98	39'	30
	18'		99	40'	31
	19'		100	41'	29
	20'		101	42'	33
	21'		102	43'	33
	22'		103	44'	29

104	45'	31	144	85'	39
105	46'	34	145	86'	45
106	47'	29	146	87'	48
107	48'	30	147	88'	48
108	49'	33	148	89'	25
109	50'	32	149	90'	41
110	51'	31	150	91'	46
111	52'	31	151	92'	48
112	53'	27	152	93'	41
113	54'	29	153	94'	40
114	55'	32	154	95'	36
115	56'	31	155	96'	38
116	57'	28	156	97'	44
117	58'	29	157	98'	21
118	59'	31	158	99'	29
119	60'	32	159	100'	28
120	61'	31	160	101'	34
121	62'	29	161	102'	39
122	63'	32	162	103'	36
123	64'	31	163	104'	39
124	65'	24	164	105'	39
125	66'	29	165	106'	40
126	67'	25	166	107'	39
127	68'	27	167	108'	40
128	69'	33	168	109'	38
129	70'	28	169	110'	41
130	71'	31	170	111'	47
131	72'	32	171	112'	47
132	73'	31	172	113'	50
133	74'	28	173	114'	53
134	75'	30	174	115'	56
135	76'	32	175	116'	60
136	77'	25	176	117'	57
137	78'	30	177	118'	65
138	79'	33	178	119'	52
139	80'	33	179	120'	62
140	81'	34	180	121'	58
141	82'	38	181	122'	58
142	83'	34	182	123'	55
143	84'	45	183	124'	60

Footmark At Reference	Embedded Depth	Blows/ Foot	Footmark At Reference	Embedded Depth	Blows/ Foot
184	125'	63		151'	
185	126'	62		152'	
186	127'	60		153'	
187	128'	59		154'	
188	129'	59		155'	
189	130'	51		156'	
190	131'	52		157'	
191	132'	62		158'	
192	133'	73		159'	
193	134'	61		160'	
194	135'	60		161'	
195	136'	53		162'	
196	137'	60		163'	
	138'			164'	
	139'			165'	
	140'			166'	
	141'			167'	
	142'			168'	
	143'			169'	
	144'			170'	
	145'			171'	
	146'			172'	
	147'			173'	
	148'			174'	
	149'			175'	
	150'			176'	

Notes: Mudline elevation was taken from PCT-2020 post survey performed on 11/04/2020

Start Time: 1:15:00 PM End TIme: 3:30:00 PM Total Time (h:mm): 2:15

Location: N346795.144 E346811.038 Plum: 0.2%NE

Inspector: Meshkat Mirzaei **Date:** 5/28/2021

Vibratory Pile Driving Record

Job Name:	PCT 2021	**Driving Date:**	5/29/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	Super Kong
Pile Name:	MD6	**Structure Name:**	MD6
Pile Length (ft):	202' 4"	**Bent #:**	-
Pile Diameter (in):	144	**Pile Wall Thick:**	-
Pile Type:	Plumb		
Final Tip Elev (ft):	-160.04	**Mudline Elev (ft):**	-32.42
Reference:	Top of template	**Reference Elev. (ft):**	32

Environmental

Tidal Stage:	High	**Attenuated:**	Yes
Tidal Movement:	Ebb	**Active # Rings:**	4
Start Water Depth (ft):	39.02	**Hammer Energy:**	-
Ending Water Depth (ft):	38.42	**Do bubbles fully encapsulate pile?**	Yes
		Approx. Max. Distance between Bubbles and Pile (ft):	~5

Compressor/ring #:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Flow Rate (cfm):	700	700	700	700			

Vibratory Pile Driving Data

Footmark at Reference		Start	Stop	Comments
Start	Stop	Time	Time	
		2:35:10 PM		MMO warning on visibility.
		2:54:01 PM		Hammer on pile
79.0	80.5	2:55:31 PM	2:55:35 PM	
80.5	87.0	2:58:45 PM	3:00:58 PM	
87.0	89.5	3:01:47 PM	3:02:02 PM	
				`

Additional Comments:

Total drive time (h:mm:ss): 0:06:31 Total Embedment (ft): 10.5

Mudline elevation was taken from PCT-2020 Post Survey performed on 11/04/2020.

Inspector Signature: Meshkat Mirzaei

Impact Pile Driving Log

Job Name:	PCT 2021	**Driving Date:**	5/29/2021
Contractor:	Pacific Pile & Marine	**Hammer Type:**	IHC S-800
Pile Name:	MD6	**Structure Name:**	MD6
Pile Length:	202' 4"	**Mudline Elev:**	-32.52'
Pile Diameter:	144"	**Reference:**	top of template
Pile Type:	Plumb	**Reference Elev:**	32'
Final Tip Elev:	-160.04'		

Environmental

Tidal Stage:	High			**Attenuated:**	Yes
Tidal Movement:	Ebb			**Active # of Rings:**	4
Start Water Depth:	32.72'	**End Water Depth:**	30.02'	**Hammer Energy:**	-
Distance between Bubbles and Pile:	~5			**Do bubbles fully encapsulate pile?**	Yes
Compressor/ring #	1	2	3	4	
CFM Flow Rate:	700	700	700	700	

Footmark At Reference	Embedded Depth	Blows/ Foot	Footmark At Reference	Embedded Depth	Blows/ Foot
	1'	Embedment due to self weight and / or vibratory hammer		23'	
	2'		94	24'	15
	3'		95	25'	46
	4'		96	26'	35
	5'		97	27'	30
	6'		98	28'	51
	7'		99	29'	28
	8'		100	30'	39
	9'		101	31'	35
	10'		102	32'	29
	11'		103	33'	26
	12'		104	34'	26
	13'		105	35'	23
	14'		106	36'	24
	15'		107	37'	25
	16'		108	38'	20
	17'		109	39'	29
	18'		110	40'	41
	19'		111	41'	33
	20'		112	42'	32
	21'		113	43'	25
	22'		114	44'	31

Footmark At Reference	Embedded Depth	Blows/ Foot	Footmark At Reference	Embedded Depth	Blows/ Foot
115	45'	30	152	82'	33
116	46'	32	153	83'	36
117	47'	30	154	84'	33
118	48'	32	155	85'	37
119	49'	34	156	86'	37
120	50'	32	157	87'	34
121	51'	33	158	88'	27
122	52'	31	159	89'	37
123	53'	33	160	90'	35
124	54'	30	161	91'	43
125	55'	28	162	92'	23
126	56'	32	163	93'	25
127	57'	29	164	94'	22
128	58'	15	165	95'	33
129	59'	32	166	96'	33
130	60'	34	167	97'	37
131	61'	37	168	98'	30
132	62'	30	169	99'	29
133	63'	35	170	100'	26
134	64'	19	171	101'	29
135	65'	25	172	102'	29
136	66'	18	173	103'	33
137	67'	33	174	104'	30
138	68'	32	175	105'	32
139	69'	36	176	106'	44
140	70'	36	177	107'	46
141	71'	32	178	108'	39
142	72'	31	179	109'	51
143	73'	28	180	110'	42
144	74'	36	181	111'	40
145	75'	27	182	112'	43
146	76'	32	183	113'	41
147	77'	29	184	114'	45
148	78'	25	185	115'	45
149	79'	34	186	116'	53
150	80'	31	187	117'	58
151	81'	34	188	118'	54

Footmark At Reference	Embedded Depth	Blows/ Foot	Footmark At Reference	Embedded Depth	Blows/ Foot
189	119'	56		145'	
190	120'	61		146'	
191	121'	62		147'	
192	122'	61		148'	
193	123'	66		149'	
194	124'	62		150'	
195	125'	60		151'	
196	126'	64		152'	
	127'			153'	
	128'			154'	
	129'			155'	
	130'			156'	
	131'			157'	
	132'			158'	
	133'			159'	
	134'			160'	
	135'			161'	
	136'			162'	
	137'			163'	
	138'			164'	
	139'			165'	
	140'			166'	
	141'			167'	
	142'			168'	
	143'			169'	
	144'			170'	

Notes: Mudline elevation was taken from PCT-2020 post survey performed on 11/04/2020

Start Time: 4:08:00 PM End Time: 5:36:00 PM Total Time (h:mm): 1:28

Location: N346936.46 E346895.60

Inspector: Meshkat Mirzaei **Date:** 5/29/2021