NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

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

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Appendices

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Appendix B: Summary Data Tables for Impact Pile Driving

Appendix C: Frequency Spectrographs for Selected Positions

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	feet
Hz	Hertz
in	inches
kHz	kilohertz
km	kilometer(s)
L_{eq}	equivalent sound level
L_{pk}	peak sound pressure level
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
SELss	single-strike SEL
SFD	South Floating Dock
SLM	Sound Level Meter(s)
SPL	sound pressure level
TL	transmission loss
V	volts
V/pC	volts per picocoulombs

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Executive Summary

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.

Pile driving during the first season of the Petroleum and Cement Terminal (PCT) Project began in April 2020 and continued into the fall, with the first bout of hydroacoustic monitoring occurring in June 2020. Measurements were made between 10 and 50 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 860-meter range and at about 2,600 meters to compute transmission loss to calculate distances to the Level A and Level B harassment zones as implemented by the National Marine Fisheries Service (NMFS) under the Marine Mammal Protection Act (MMPA). Measurements were conducted for the following pile installation activities:

1. Vibratory installation of four 24-inch template piles (attenuated with an air bubble casing)
2. Vibratory installation of six 24-inch temporary trestle piles (attenuated with an air bubble casing)
3. Vibratory installation of five 36-inch template piles (attenuated with an air bubble casing)
4. Vibratory installation of ten 48-inch piles (attenuated with an air bubble casing)
5. Vibratory installation of one 48-inch piles (unattenuated)
6. Impact pile driving of eleven 48-inch piles (attenuated with an air bubble casing)
7. Impact pile restrike of two 48-inch piles (attenuated with an air bubble casing)
8. Vibratory installation of five 72-inch air bubble casings (unattenuated)
9. Vibratory removal of one 36-inch temporary pin pile (attenuated since in very shallow water).

Table ES-1 summarizes the average extent of zones used to assess Level A and Level B harassment for each size of pile during vibratory installation. Table ES-2 summarizes the averages distance to these zones during impact driving. Table ES-1 and Table ES-2 address only the accumulated sound exposure level (SEL) thresholds to assess Level A and Level B harassment. The highest measured peak sound pressures for impact driving sounds were below the thresholds for all of the hearing groups except high-frequency cetaceans. The computed mean 10-meter peak sound pressure for all pile driving at 10 meters was 205 decibels (dB) with a range of 195 to 210 dB. Levels above the threshold of 202 dB were computed to extend out 17 meters when using the average for all pile driving and 39 meters when considering the loudest pile driving event. To assess Level B harassment, the ambient sound level of 122.2 dB that was measured in 2016 was used (Austin et al. 2016).

NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

Table ES-1. Average distances to the Level A and Level B harassment zones during vibratory installation

Type / Size of Pile	Species Hearing Group	Level A		Level B	
		Threshold (dB)	Distance (meters)	Threshold (dB)	Distance (km)
Vibrate 24-inch Trestle with air bubble casing	Low-Frequency Cetaceans (e.g., humpback whale)	199	2	122.2	5.1
	Mid-Frequency Cetaceans (e.g., beluga whale)	198	<1		
	High-Frequency Cetaceans (e.g., harbor porpoise)	173	6		
	Phocids (e.g., harbor seal)	201	<1		
	Otariids (e.g., sea lion)	219	2		
Vibrate 24-inch Template with air bubble casing	Low-Frequency Cetaceans	199	1	122.2	3.7
	Mid-Frequency Cetaceans	198	<1		
	High-Frequency Cetaceans	173	5		
	Phocids	201	<1		
	Otariids	219	<1		
Vibrate 36-inch Trestle with air bubble casing	Low-Frequency Cetaceans	199	4	122.2	5.5
	Mid-Frequency Cetaceans	198	<1		
	High-Frequency Cetaceans	173	4		
	Phocids	201	<1		
	Otariids	219	2		
Vibrate 48-inch Permanent (attenuated only)	Low-Frequency Cetaceans	199	2	122.2	23.7[a]
	Mid-Frequency Cetaceans	198	<1		
	High-Frequency Cetaceans	173	4		
	Phocids	201	<1		
	Otariids	219	<1		
Vibrate 48-inch Permanent (unattenuated only)	Low-Frequency Cetaceans	199	10	122.2	7.0 [a]
	Mid-Frequency Cetaceans	198	4		
	High-Frequency Cetaceans	173	28		
	Phocids	201	6		
	Otariids	219	<1		
Vibrate 72-inch casings	Low-Frequency Cetaceans	199	<1	122.2	1.5
	Mid-Frequency Cetaceans	198	<1		
	High-Frequency Cetaceans	173	2		
	Phocids	201	<1		
	Otariids	219	<1		
Vibratory 36-inch Pin Pile Removal (out of water)	Low-Frequency Cetaceans	199	<1	122.2	2.6
	Mid-Frequency Cetaceans	198	<1		
	High-Frequency Cetaceans	173	<1		
	Phocids	201	<1		
	Otariids	219	<1		

[a] See Section 6.4.1 for discussion regarding larger distances to Level B for unattenuated vs. attenuated conditions.
Note: dB = decibel(s): km = kilometer(s); m = meter(s).

Table ES-2. Average distances to the Level A and Level B harassment zones during impact installation

Type / Size of Pile	Species Hearing Group	Level A		Level B	
		Threshold (dB)	Distance (m)	Threshold (dB)	Distance (km)
Impact Hammer					
48-inch Permanent (attenuated only)	Low-Frequency Cetaceans	183	346	160	2.3
	Mid-Frequency Cetaceans	185	5		
	High-Frequency Cetaceans	155	114		
	Phocids	185	43		
	Otariids	203	3		

Note: dB = decibel(s); km = kilometer(s); m = meter(s).

Summary of Acoustic Data – Vibratory Installation of Attenuated 24-inch Template Piles

Measurements were made for a total of four 24-inch-diameter template piles that were installed with a vibratory hammer through an air bubble casing. The computed overall transmission loss coefficient (assuming a Log_{10} falloff rate) that was computed from the data regression is shown, along with the computed 10-meter level. Sound pressure level (SPL) in dB referenced to a pressure of 1 microPascal (dB re 1 µPa) is plotted over distance in meters. The median of the root mean square (RMS) sound level pressures for each pile driving event are plotted by distance on Figure ES-1 using only data for sound propagating outwards into the Knik Arm (excluding South Floating Dock (SFD) data). Each of the four colors indicates the data from a single pile collected at different distances from the pile location. Note the considerable variability at the farthest measurement position where sound levels were lowest.

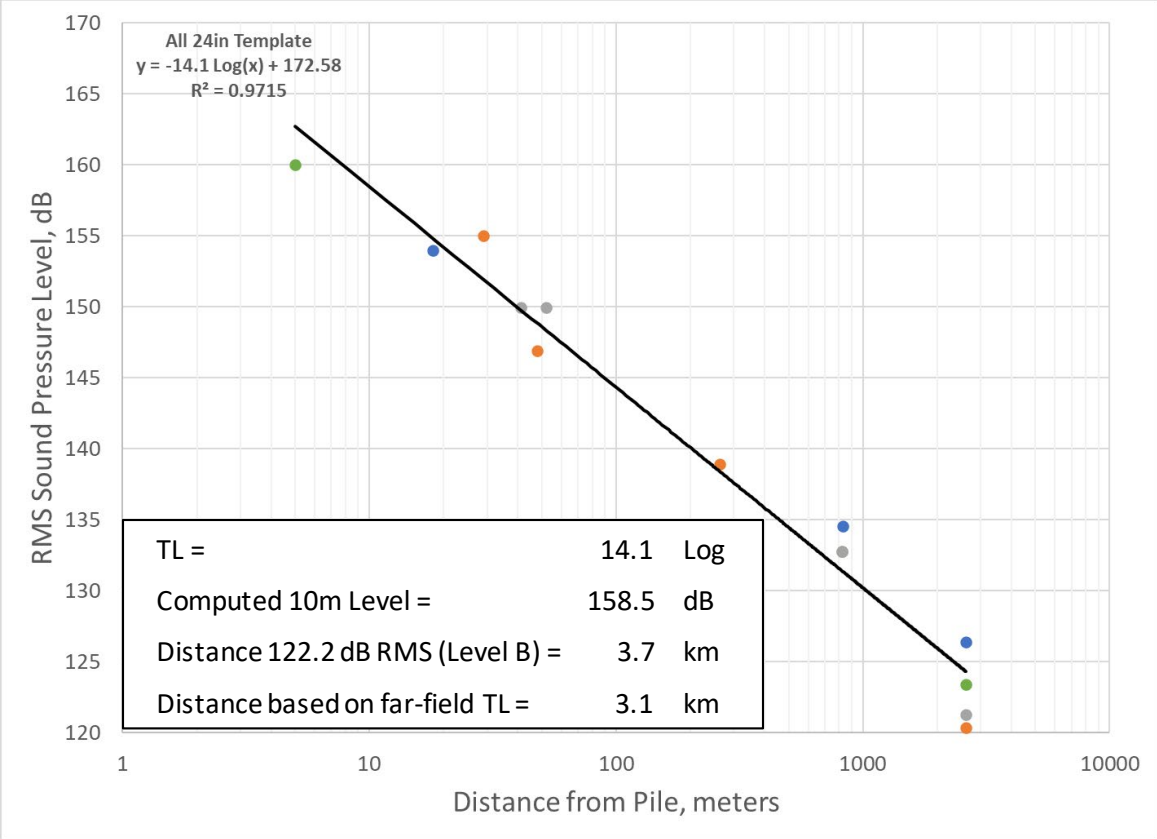

Figure ES-1. RMS SPLs for 24-inch-diameter template piles installed with a vibratory hammer and air bubble casing

Summary of Acoustic Data – Vibratory Installation of 24-inch Temporary Trestle Piles

Measurements were made for a total of six 24-inch-diameter temporary trestle piles that were installed with a vibratory hammer through an air bubble casing. These data summarized the RMS levels for near source (10 to 20 meters) and the far-field (0.6 to 2.6 kilometers [km]). The median of the RMS sound level pressures for each pile driving event are plotted by distance on Figure ES-2 using only data for sound propagating outwards into the Knik Arm (excluding SFD data). Each of the six colors indicates the data from a single pile collected at different distances from the pile location.

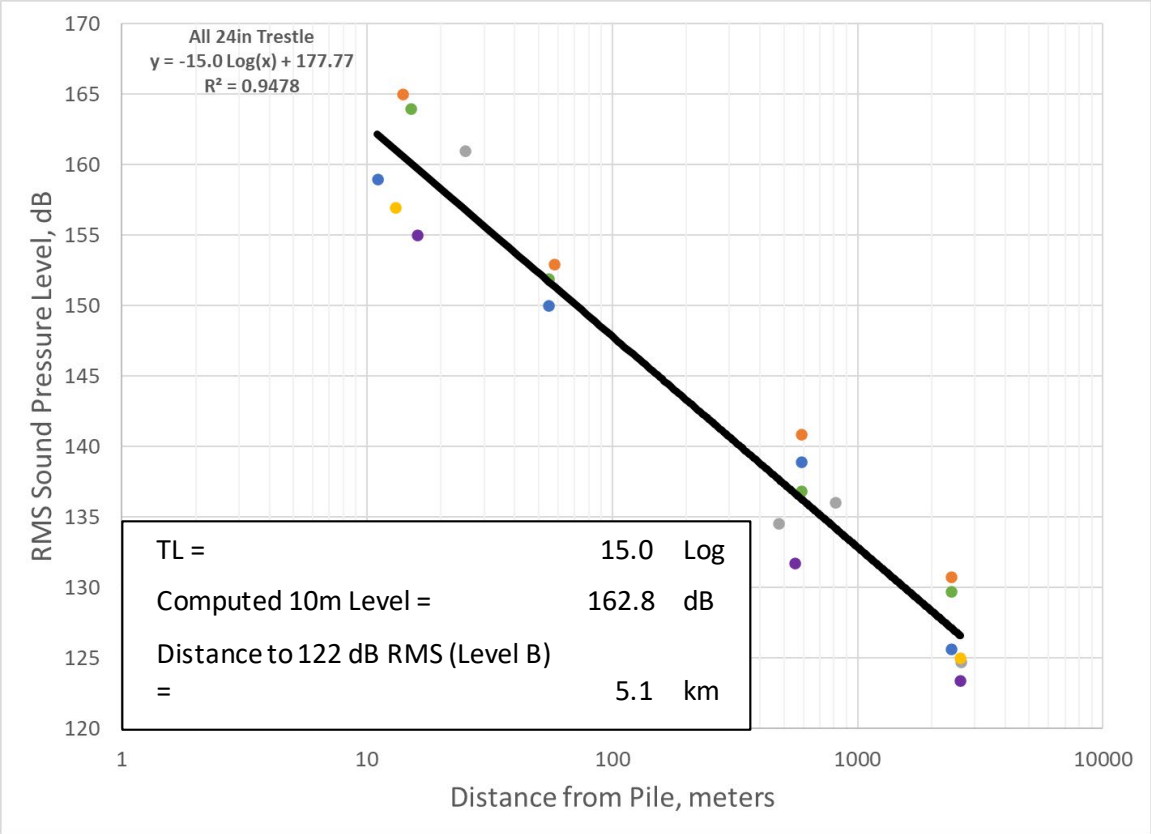

Figure ES-2. RMS SPLs for 24-inch-diameter temporary trestle piles installed with a vibratory hammer and bubble curtain

Summary of Acoustic Data – Vibratory Installation of 36-inch Temporary Trestle Piles

Measurements were made for a total of five 36-inch-diameter temporary trestle piles that were installed with a vibratory hammer through an air bubble casing. Note that for the entire project, only these five temporary trestle piles were driven in water deeper than 3 meters. These data summarized the RMS levels for near source (10 to 20 meters) and the far-field (0.6 to 2.6 km). The median of the RMS sound level pressures for each pile driving event are plotted by distance on Figure ES-3 using only data for sound propagating outwards into the Knik Arm (excluding SFD data). Each of the five colors indicates the data from a single pile collected at different distances from the pile location.

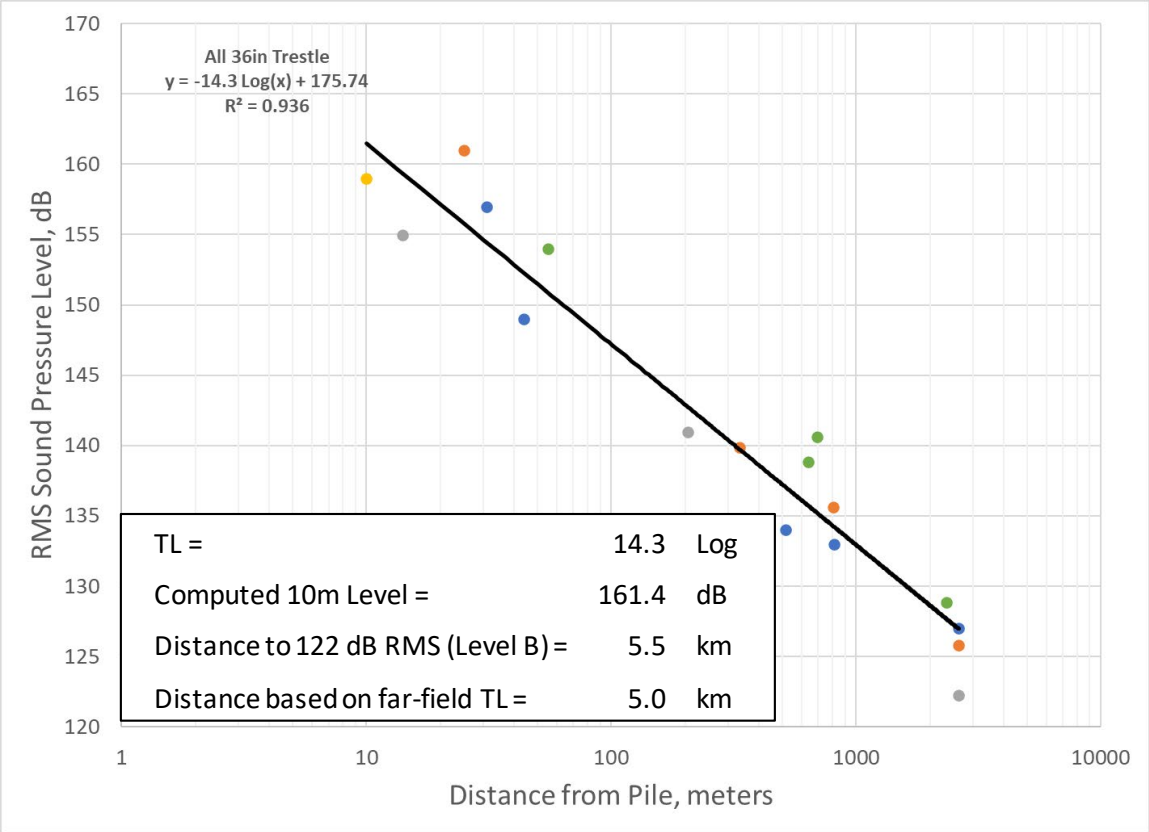

Figure ES-3. RMS SPLs for 36-inch-diameter temporary trestle piles installed with a vibratory hammer and bubble curtain

Summary of Acoustic Data – Vibratory Installation of 48-inch Permanent Piles

Measurements were made for a total of ten permanent 48-inch-diameter permanent piles (two Access Trestle and eight Platform) that were installed with a vibratory hammer through an air bubble casing. The measured sound levels show considerable scatter for these piles. Note that there was a roughly 5- to 10-dB range in sound levels for different pile driving events in the far field. The driving periods typically ranged from 15 to 30 minutes. Over the course of a single driving event, sound levels varied by about 5 dB. The median of the RMS sound level pressures for each pile driving event are plotted by distance on Figure ES-4 using only data for sound propagating outwards into the Knik Arm (excluding SFD data). Each of the colors indicates the data from a single pile collected at different distances from the pile location. Note that the large Level B zone was computed to extend well beyond the measurement range. In addition, the computation for this zone was greatly influenced by measurement results for three events (Piles A-1, D-1, and C-2). The transmission loss coefficients computed for these three events were quite low, resulting in computed Level B distances of 51 to 759 km, which is well beyond the measurement range of the study that went out about 2.8 km. The low transmission loss for these piles was due to the presence of very low-frequency sound components.

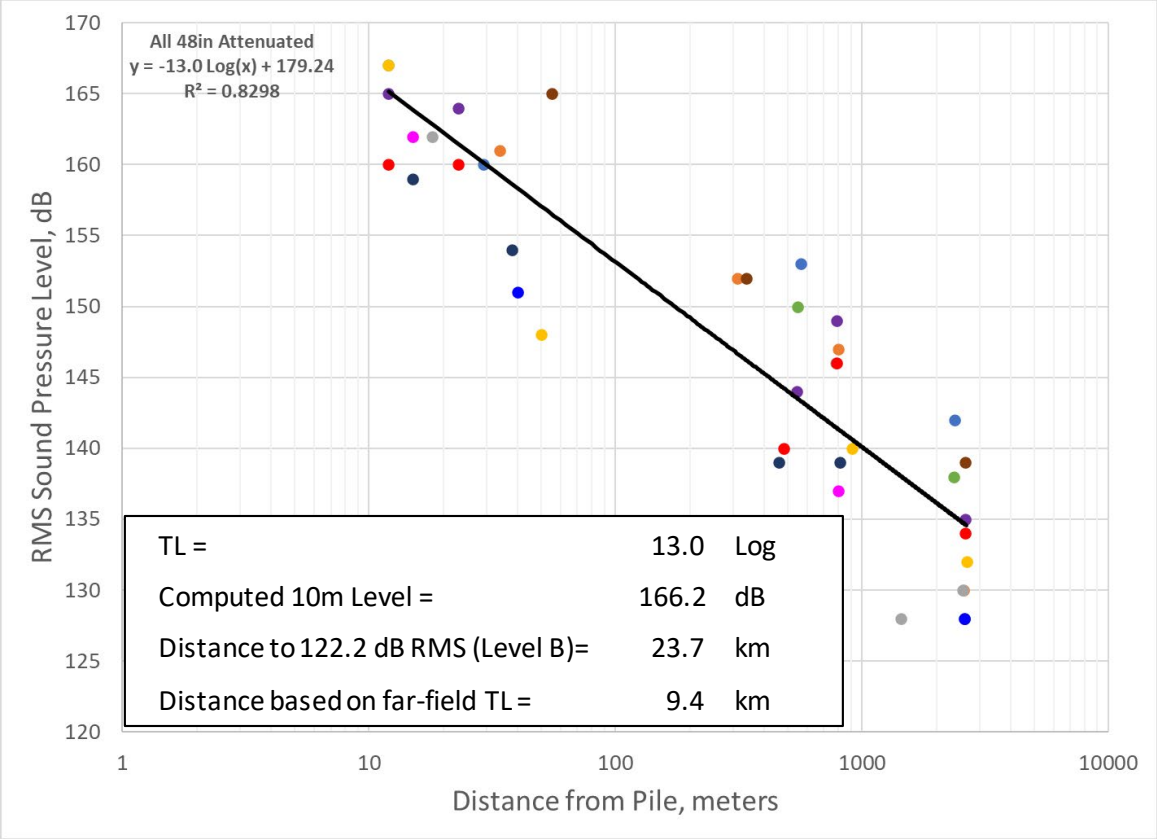

Figure ES-4. RMS SPLs for 48-inch-diameter piles installed with a vibratory hammer and air bubble casing

Summary of Acoustic Data – Vibratory Installation of an Unattenuated 48-inch Permanent Pile

Measurements were conducted when a 48-inch-diameter pile was installed with a vibratory hammer without an air bubble casing. Pile B-1, which was suspected to have run into an obstruction, was installed using a vibratory hammer without an air bubble casing and was then impact driven with the air bubble casing. A special guide, which would not accommodate the air bubble casing, had to be used for this pile. This guide may have caused elevated sounds at the beginning of the driving event as the pile would wobble and contact the guide until it became stable. The median of the RMS sound level pressures for each pile driving event are plotted by distance on Figure ES-5 using only data for sound propagating outwards into the Knik Arm (excluding SFD data). While near-source levels were higher than attenuated levels, the sounds from this pile decreased at a greater rate with distance than measured with attenuated piles. Interestingly, the computed distance to the Level B zone was less than the attenuated conditions.

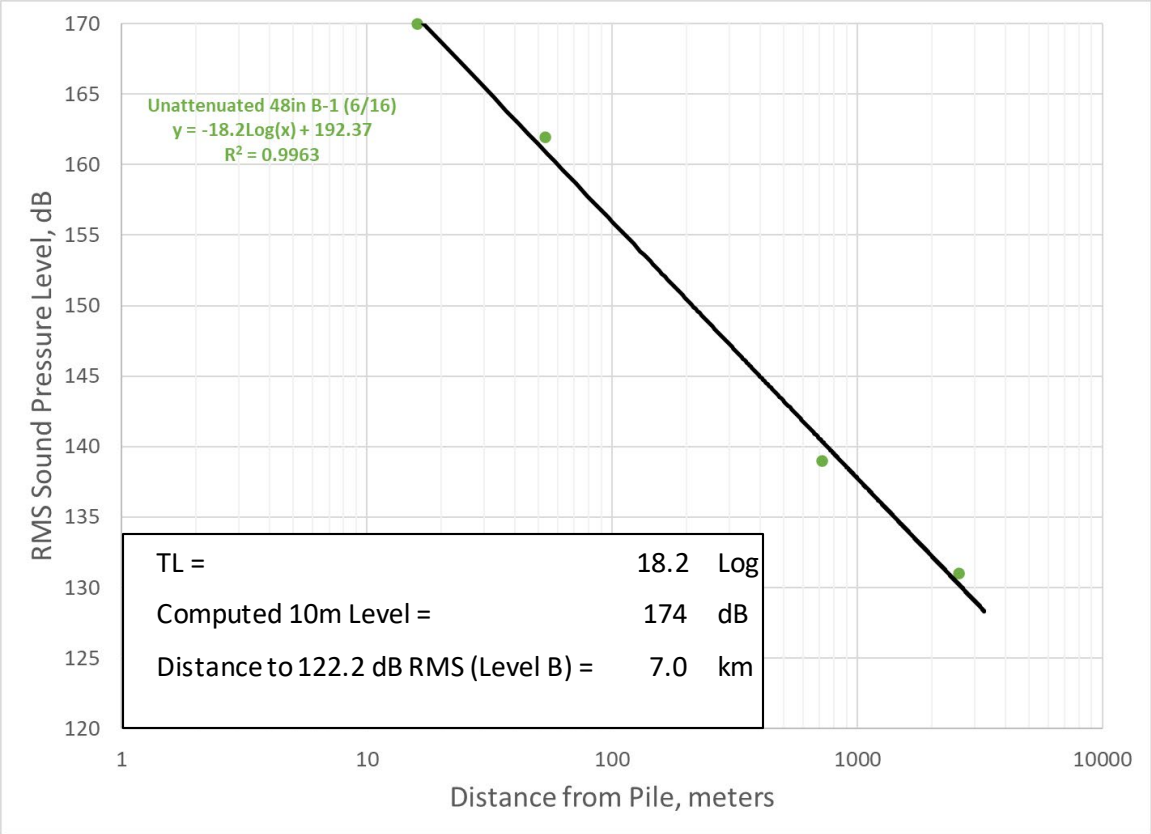

Figure ES-5. RMS SPLs for a single unattenuated 48-inch-diameter pile installed with a vibratory hammer

Summary of Acoustic Data – Impact Installation of 48-inch Permanent Piles with a Bubble Casing

Measurements were made for impact driving of 11 permanent 48-inch-diameter permanent piles. This included the driving of one pile, B-2, on 2 separate days (due to obstruction issues) and the restrike of Pile A-1. There were 13 sets of measurements collected for impact pile driving. The median of the maximum peak pressures for each pile driving event are plotted by distance on Figure ES-6 using only data for sound propagating outwards into the Knik Arm (excluding SFD data). Each of the colors indicates the data from a single pile collected at different distances from the pile location.

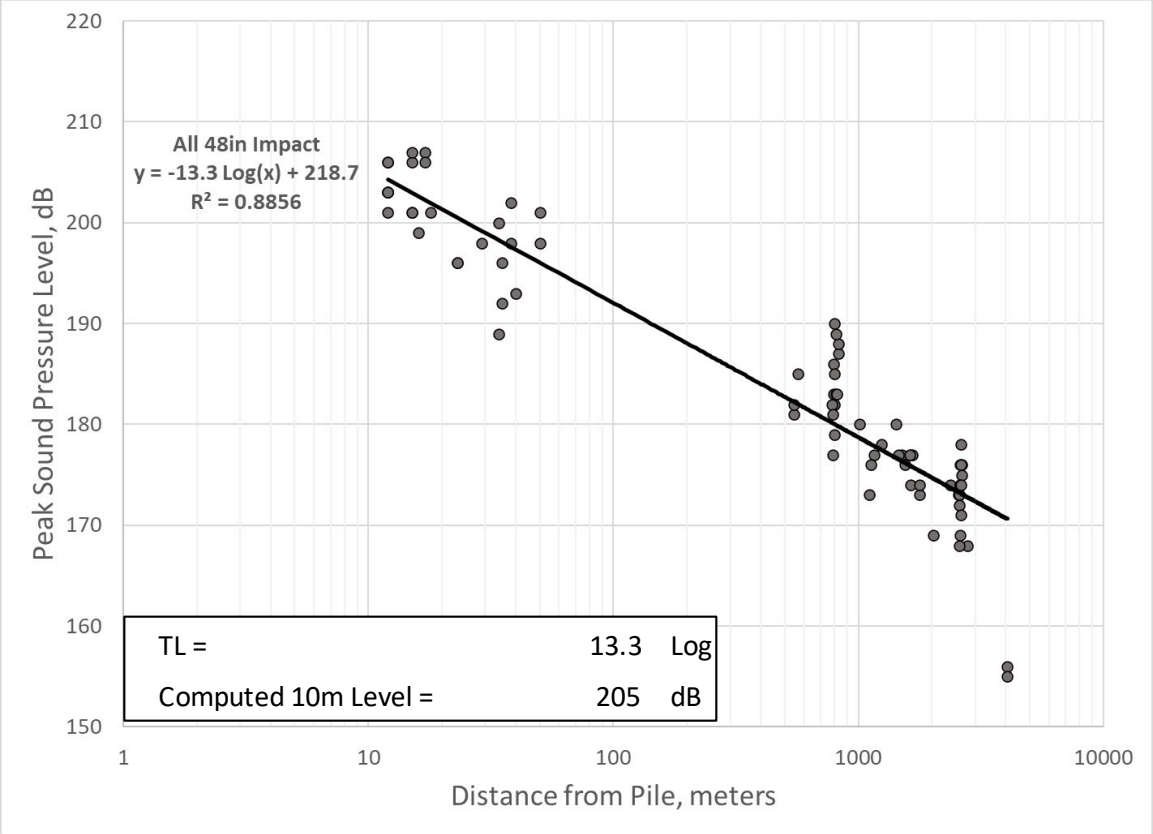

Figure ES-6. Peak sound pressures for impact driving 48-inch-diameter piles with a bubble casing

The SEL for each acoustic pulse was measured. The median pulse for each pile driving event is plotted by distance on Figure ES-7 using only data for sound propagating outwards into the Knik Arm (excluding SFD data).

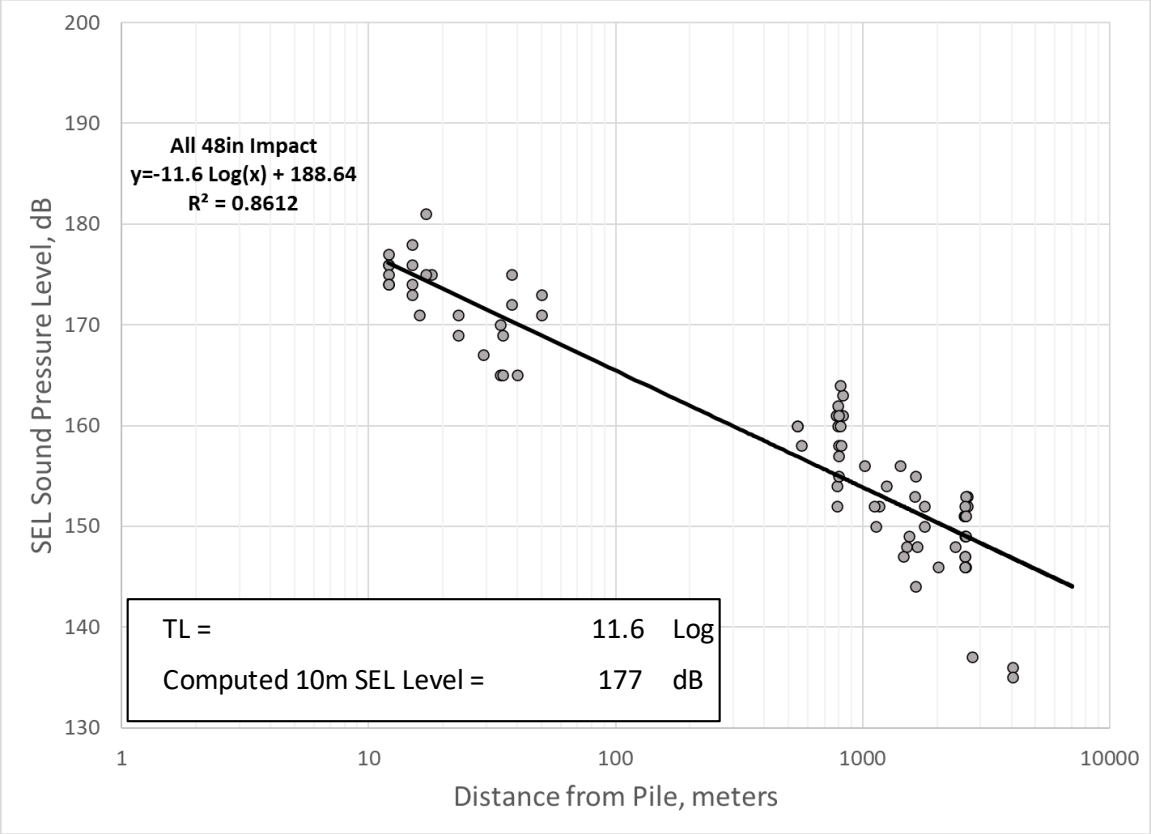

Figure ES-7. SELs for impact driving 48-inch-diameter piles with a bubble casing

The median RMS SPL, computed over individual acoustic pulses, is plotted by distance on Figure ES-8 using only data for sound propagating outwards into the Knik Arm (excluding SFD data). Note that the magnitude of the RMS levels is dependent on the pulse duration, where a shorter pulse results in a higher RMS level. For the most part, pulse duration ranged from 0.05 to 0.11 seconds.

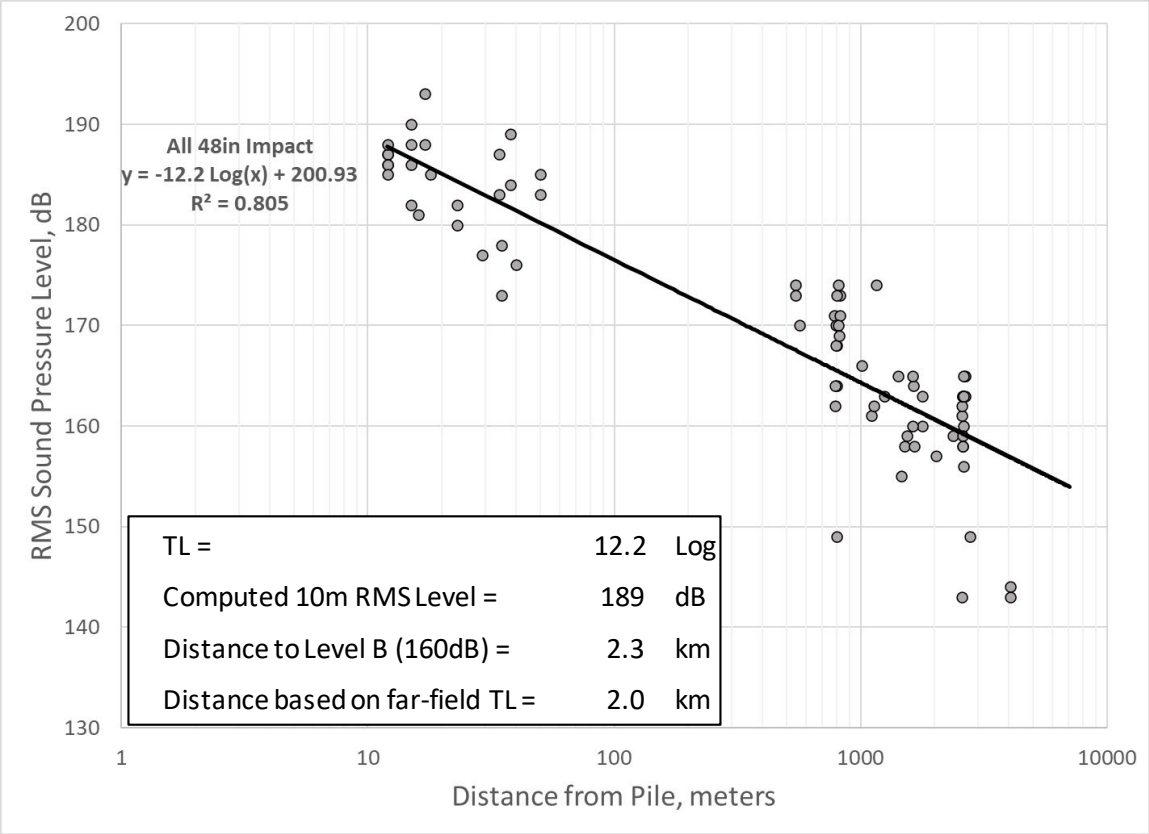

Figure ES-8. RMS SPLs for impact driving 48-inch-diameter piles with a bubble casing

Summary of Acoustic Data – Unattenuated Vibratory Installation of 72-inch Bubble Casings

The bubble casings for the 48-inch-diameter permanent piles as shown on Figure ES-9 were seated in the sediment for stability using a vibratory driver. These were relatively short driving periods of less than 10 minutes. These casings are driven with the smaller ICE 44-B Vibe hammer.

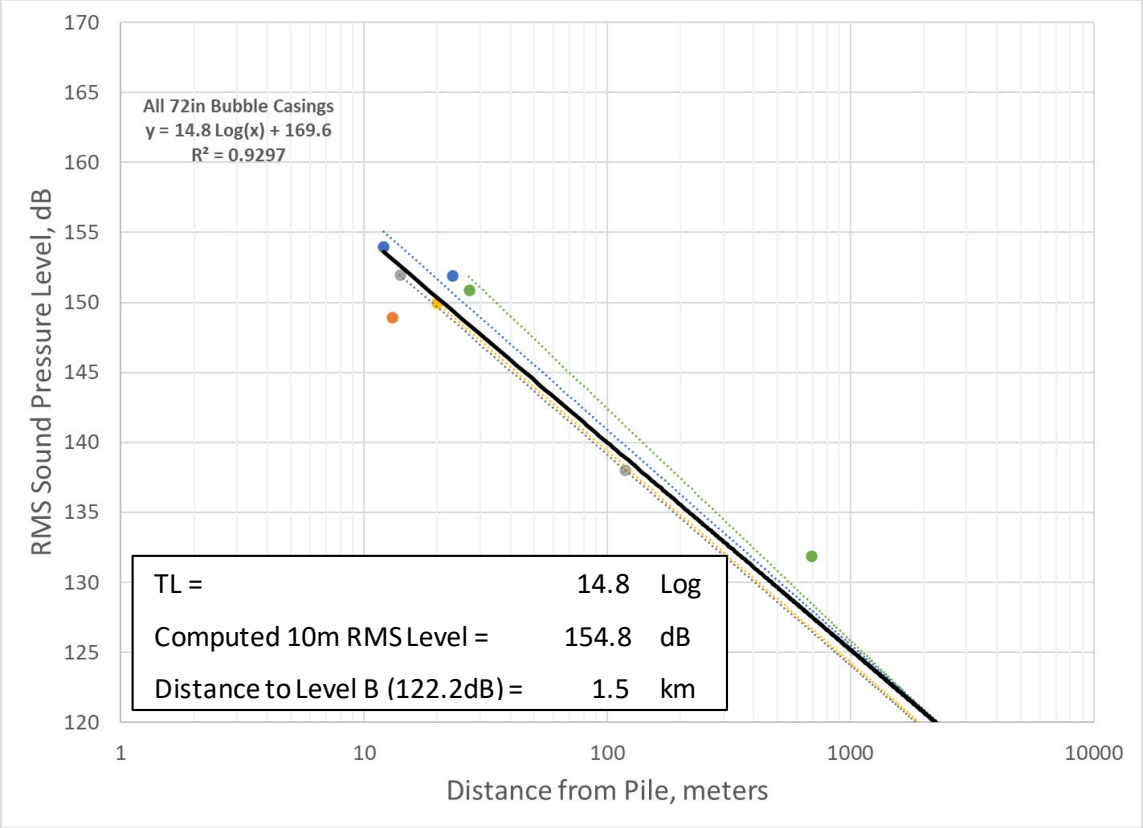

Figure ES-9. RMS SPLs for unattenuated vibratory installation of 72-inch-diameter bubble casings

NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

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 will involve 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 current PCT design includes both an access trestle (bridge-like structure allowing access to the loading platform) and a temporary construction work trestle. Following construction of the access trestle, the temporary construction work trestle piles will be removed.

The PCT Project pile driving will be conducted over two construction seasons. The first season started in April 2020 and is expected to be completed by March 31, 2021, and the second season is expected to start April 1, 2021, and be completed by March 31, 2022.

This document summarizes the methods and equipment used, as well as the results, for underwater hydroacoustic monitoring completed during vibratory and impact pile driving operations in June 2020. This work was part of the PCT Project, which is a component of the PAMP intended to replace the existing Petroleum Oil Lubricants Terminal with a new structure that exceeds current seismic standards. 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).

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

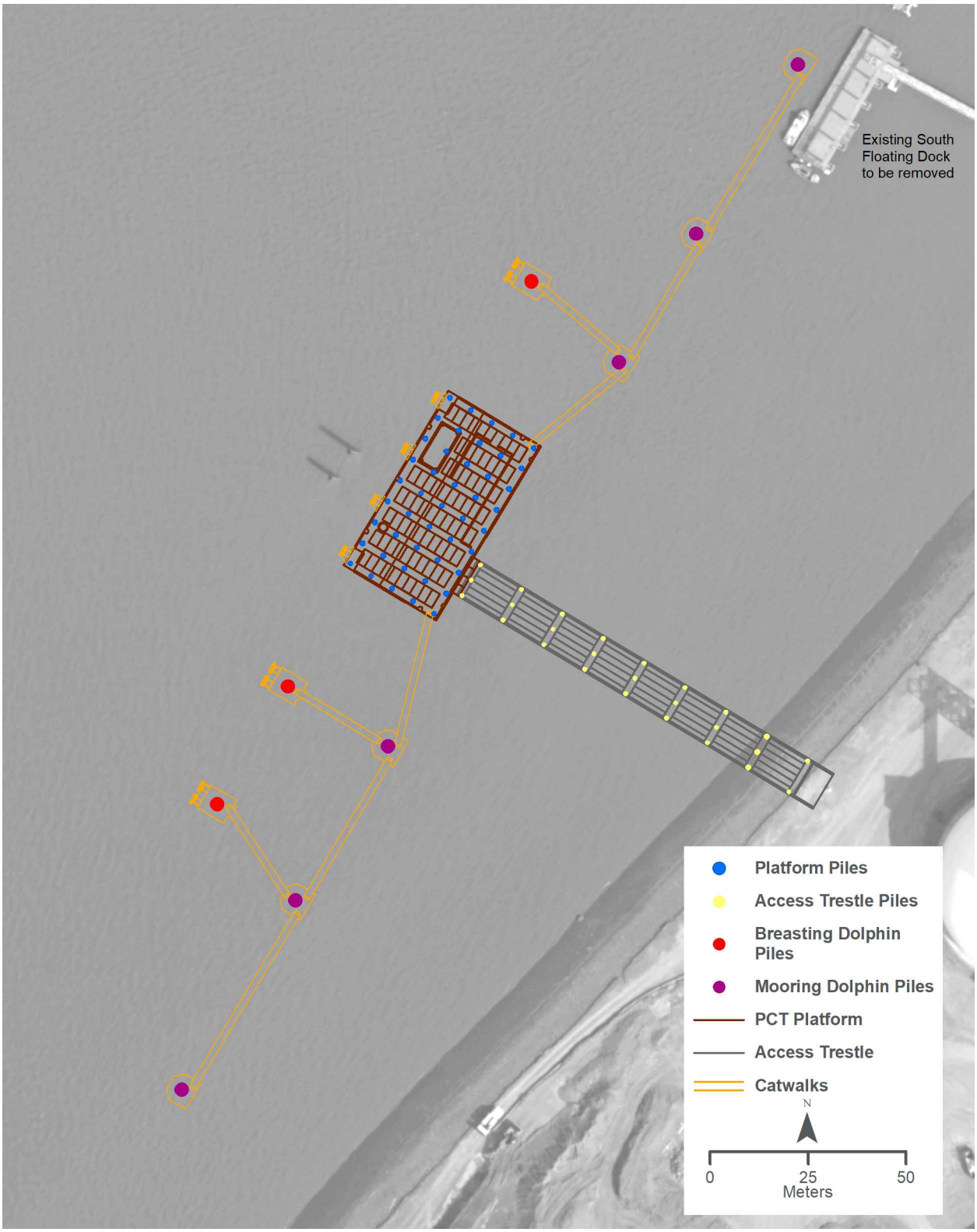

Figure 1-2. Project footprint and pile locations for the Proposed PCT (both seasons) (Note that only the access trestle and platform piles were driven during 2020.)

1.1 Project Description

The PCT terminal platform will have a surface area of 15,300 square feet and will be supported by approximately 45 round, 48-inch-diameter steel pipe piles. The platform will connect to the shore by the access trestle, have a surface area of 11,254 square feet, and be supported by 26 round, 48-inch-diameter steel pipe piles. Six mooring dolphins and three breasting dolphins will each consist of a single round, 144-inch-diameter steel pipe pile. The mooring dolphins will be constructed parallel to and landward of the loading platform face, and the breasting dolphins will be constructed parallel to the PCT loading platform face (Figure 1-3). Catwalks will be installed above the water to connect the dolphins and loading platform. The access trestle is comprised of eight bents (clusters) of three piles each and one bent of two piles at the abutment (Figure 1-4).

Measurements of in-water pile installation and removal during the 2020 season included:

1. Vibratory installation of four 24-inch template piles (attenuated with an air bubble casing)
2. Vibratory installation of six 24-inch temporary trestle piles (attenuated with an air bubble casing)
3. Vibratory installation of five 36-inch template piles (attenuated with an air bubble casing)
4. Vibratory installation of ten 48-inch piles (attenuated with an air bubble casing)
5. Vibratory installation of one including one 48-inch piles (unattenuated)
6. Impact pile driving of eleven 48-inch piles (attenuated with an air bubble casing)
7. Impact pile restrikes of two 48-inch piles (attenuated with an air bubble casing)
8. Vibratory installation of five 72-inch air bubble casings (unattenuated)
9. Vibratory removal of one 36-inch temporary pin pile (attenuated since in very shallow water).

Note that proofing of temporary trestle piles using an impact hammer was conducted for those piles driven out of water.

For pile driving completed in June 2020, a Delmag D-180 diesel impact hammer was used to install the 48-inch piles. An APE 300-6 vibratory hammer was used for setting all the permanent 48-inch piles, the temporary 36-inch piles, and the temporary 24-inch piles. An APE 200-6 vibratory hammer was used for the temporary thick-walled 24-inch template piles installed for the access trestle. A smaller ICE 44-B vibratory hammer was used for the installation of 72-inch-diameter air bubble casings used to attenuate sounds from the 48-inch platform piles.

The first round of hydroacoustic monitoring 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 event 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 installation of four 72-inch-diameter air bubble casings and the removal of one 36-inch pin pile were also measured. Impact pile driving monitoring was completed for eleven 48-inch piles.

Figure 1-3 shows the different piles that were measured. Note that only 48-inch permanent piles were impact driven. Note the air bubble casing surrounding a 24-inch and a 36-inch pile.

Figure 1-3. Different piles installed, temporary 24- and 36-inch piles in foreground, with 48-inch piles in the background

The two primary driving methods used are shown on Figure 1-4.

(a) Vibratory installation of 36-inch pile (b) Impact installation of 48-inch pile

Figure 1-4. Pile driving during the acoustic measurements

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 [mi]) 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 mi) before widening to as much as 8 km (5 mi) 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 mi). The distance from the POA (east side) to nearby Port MacKenzie (west side) is approximately 4.9 km (3 mi).

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 [ft]), and the maximum water level has been measured at more than 12.5 meters (41 ft) 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 ft 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

Overall goals for the PCT Hydroacoustic Monitoring Plan during 2020 are listed below.

- Measure SPLs at approximately 10 meters from the pile during pile installation to verify estimated sound source levels. *Due to limited access to construction sites, configuration of structures, construction barge, and strong tidal currents, hydrophone positions were established at 10 to 50 meters from piles[1]. An attempt to measure at 10 to 20 meters (preferably 10 meters) was made for each pile driving event.*
- 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 hydrophone that was 600 to 860 meters away was established.*
- Measure SPLs at a distance of approximately 3 km from the pile to aid in estimation of transmission loss (TL) rates. *A fixed mooring with hydrophone that was about 2,600 meters away was established.*

The monitoring for the first season of the PCT measured and recorded sounds with the following objectives:

- A sample size of five to ten piles of each size (24-inch piles, 36-inch piles, and 48-inch piles) was measured. *Measurements were made for vibratory installation of eight 24-inch piles, vibratory installation of five 36-inch piles, vibratory installation of twelve 48-inch piles, impact installation of eleven 48-inch piles (plus two restrike events), and one vibratory removal of a 36-inch pin pile. The vibratory installation of one 48-inch pile was conducted without an air bubble casing due to constructability issues.*
- Of the piles that will be measured, one to two piles of each size may be measured during proofing using impact installation methods if logistics are able to be worked out (proofing of piles generally is limited to a short time frame, approximately 5-10 min). *All proofing of piles was conducted for piles driven outside the water in mud prior to the monitoring.*
- Vibratory installation of the bubble casing for one to two permanent piles of each size will be measured. *Measurements were conducted for four installations of 72-inch air bubble casings.*

[1] Note that in one case a measurement was made at 5 meters, and in another case at 55 meters from the pile.

1.4 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 root-mean-square (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 entire pile driving event, $P^2(t)$ is the instantaneous pressure squared, and P_{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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NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

2. Monitoring Methods and Equipment

Two pile installation operations occurred simultaneously in June 2020, as shown on Figure 2-1. One operation occurred from the temporary trestle that was accessed from the shore. The second operation occurred from the barge. Hydroacoustic monitoring was conducted for both operations.

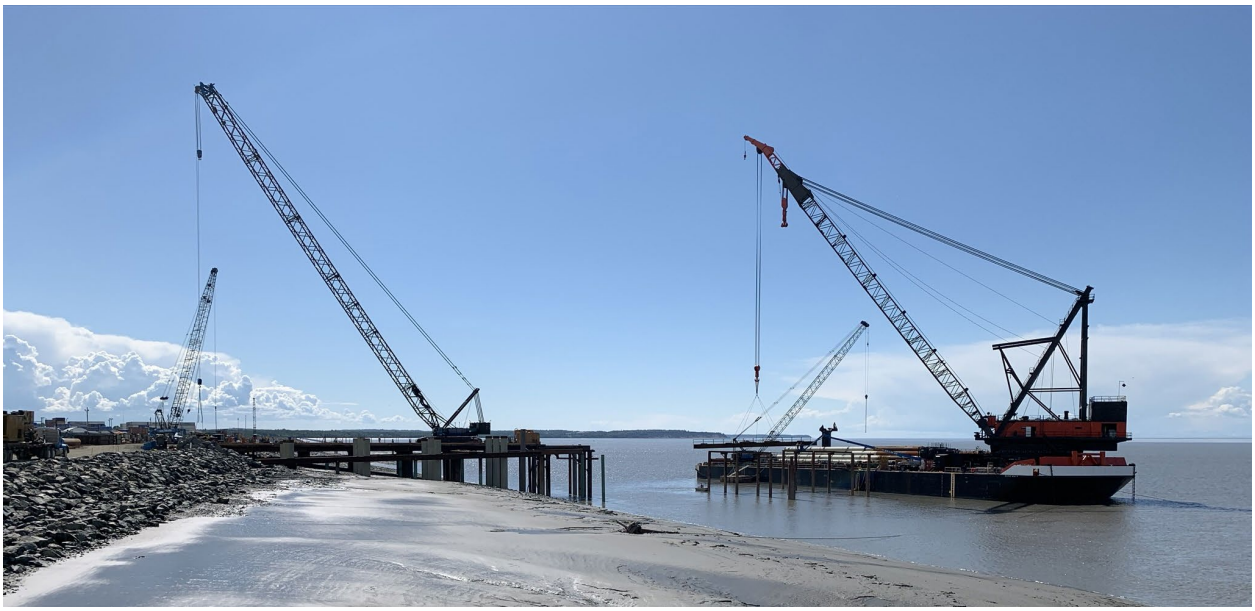

Figure 2-1. Trestle (left) and barge (right) pile installation activities, as viewed from the South Floating Dock

2.1 Monitoring Locations and Setup

Three primary measurement locations were planned for this project: (1) 10 to 20 m 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. A supplemental position was added at the South Floating Dock (SFD). While measurements were attempted at 10 meters, access to the barge and temporary trestle were not feasible most of the time or would have obstructed the sound field. The nearest unobstructed measurements possible were made. Figure 2-2 shows the project area and general measurement positions.

All close-in hydrophones were deployed from the construction barge or temporary trestle structure. Unattended hydrophones were deployed from the end of the temporary trestle prior to construction activities at positions that were typically 10 to 30 meters from the pile. These positions could not be accessed during construction. For barge operations, hydrophones were deployed from the barge and, when possible, from the construction platforms within 10 to 20 meters of the pile.

The first mooring position, which was targeted for deployment at 1 km, was typically located approximately 600 to 900 meters from the piles. This mooring position was located in an area of high tidal currents and moving sediments. The hydrophone equipment was lost or had to be retrieved multiple times. The targeted mooring position of 3 km was located across the 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. 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.

Figure 2-2. Project area showing general monitoring positions

The hydrophone placed at the SFD position was deployed from the south floating dock and was unmanned. Typically, these measurements were about 150 meters from the pile driving activities; however, this hydrophone did not fall in the same direction as the other hydrophones. The close-in positions and mooring positions followed along a line in the same direction, which ran mostly east and west. The SFD hydrophone was located to the north of the pile driving activities.

During many pile driving events, drift data were also taken from a vessel to supplement far-distant data. Due to currents, most of these measurements were made as the vessel drifted from south to north or vice versa in the tidal current (see blue outlined area on Figure 2-2. A hydrophone was deployed from the drifting vessel in the channel. Distances of the drift data ranged from less than 200 to nearly 1,900 meters from the pile driving activities.

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 SLM). Figure 2-3 shows an example of this setup. The dipping method was used for

deployment of these hydrophones (i.e., the hydrophones were deployed from a structure and weighted). This type of setup and deployment method was also used for the drift data.

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 2-4 shows the autonomous units.

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 autonomous units equipped with either the Reason Model TC-4013 systems described above or a Loggerhead Snap unit, which included a 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 imbedded in a circuit board housed in the Loggerhead unit. Figure 2-5 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 2-6 shows both deployment methods used for this project.

Tidal changes in the 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 hydrophones (see Figure 2-7), 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 both 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 duration of the 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	6	Capture underwater sound pressures and convert to voltages that can be recorded/analyzed by other equipment.
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	Record pile driving sound levels at hydrophone position.
GRAS 42AA & 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 records 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; kHz = kilohertz; V = volts; mV/pC = microvolts per picocoulombs; V/pC = volts per picocoulombs

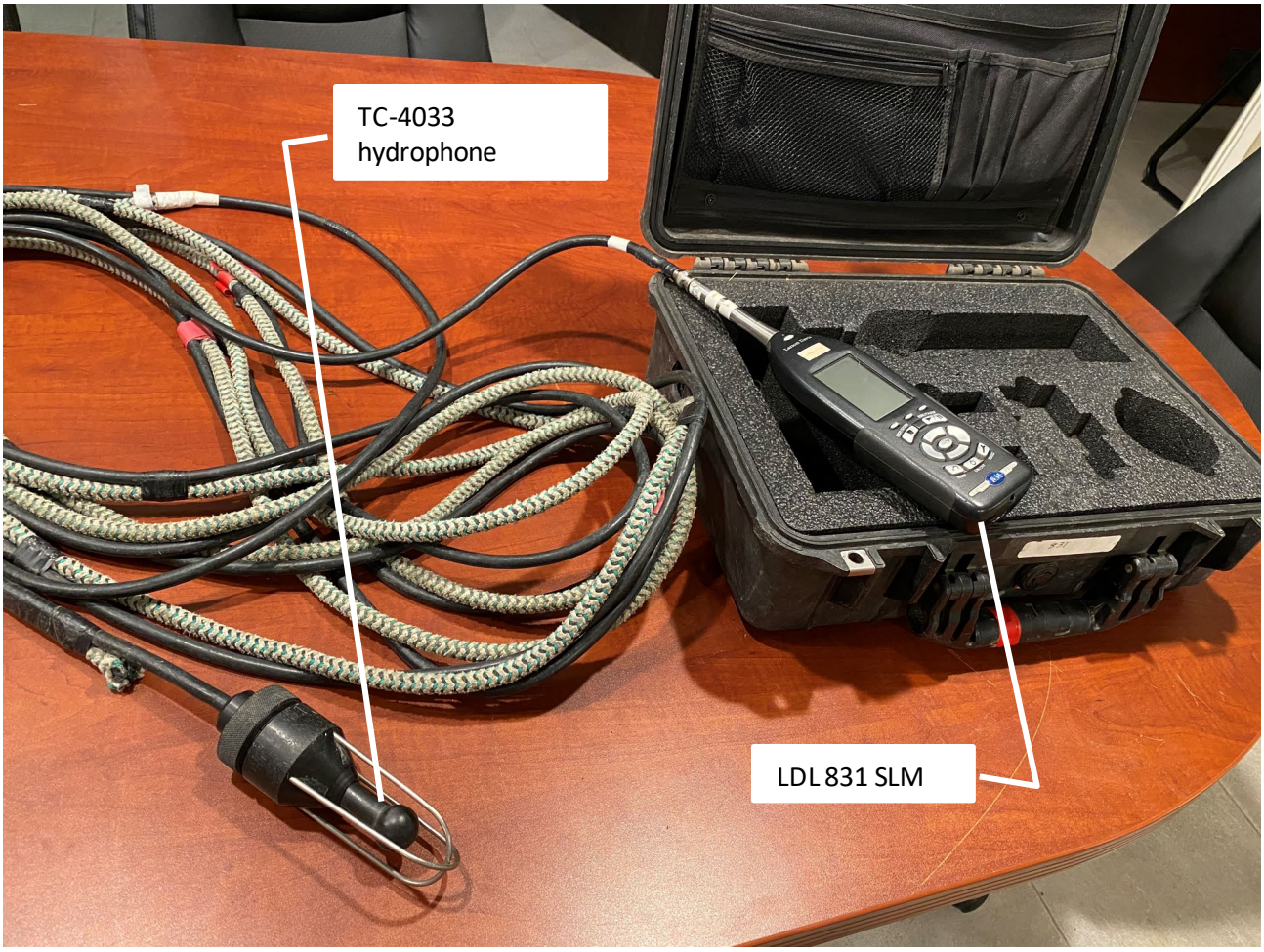

Figure 2-3. Typical hydrophone system used at the close-in, SFD, and drifting vessel positions

Figure 2-4. Autonomous units used at the close-in, SFD, and mooring positions

Figure 2-5. Loggerhead Snap units used at the mooring positions

Dipping hydrophone system, deployed from drifting vessel

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

Figure 2-6. Example of hydrophone deployments

Figure 2-7. 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 156.4 dB re 1 µPa tone for the TC-4033 hydrophones at 250 Hz. For the TC-4013 hydrophones, the calibration tone is 165.4 dB, while the Loggerhead Snap units generated a tone of 163.4 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. Such notebook entries include 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 2-8through Figure 2-10. 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. Note that 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.

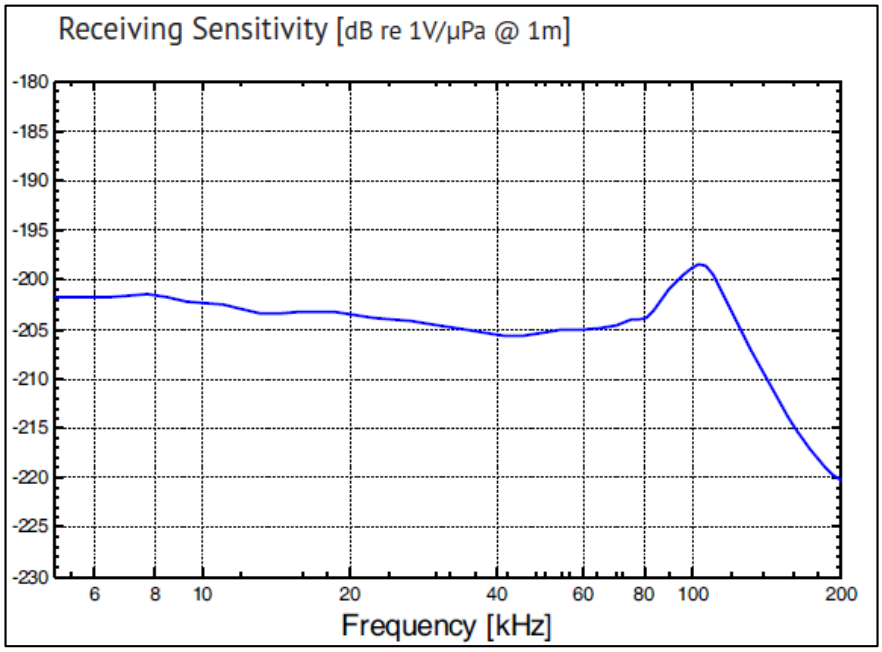

Figure 2-8. Frequency response of the TC-4033 hydrophones

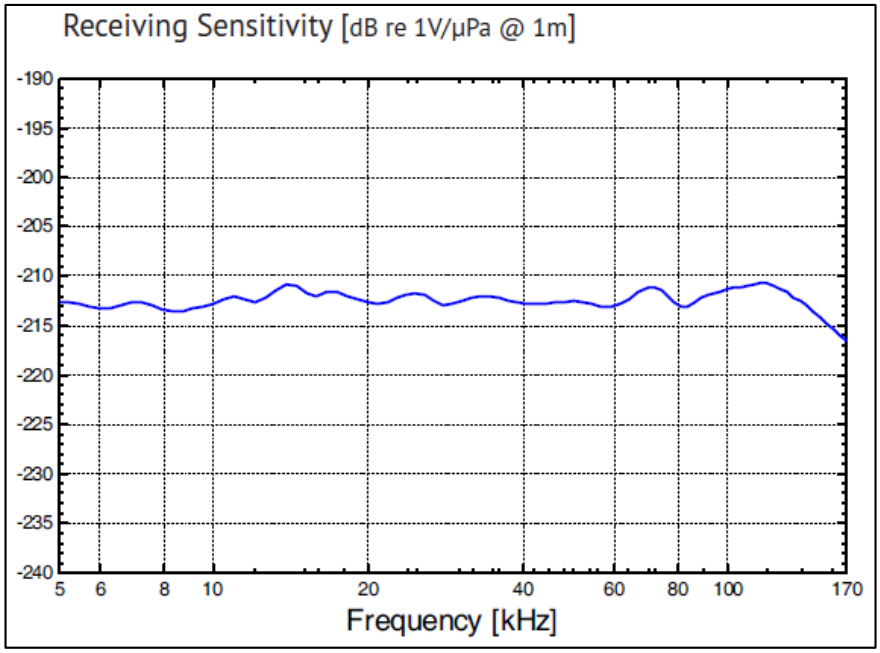

Figure 2-9. Frequency response of the TC-4013 hydrophones

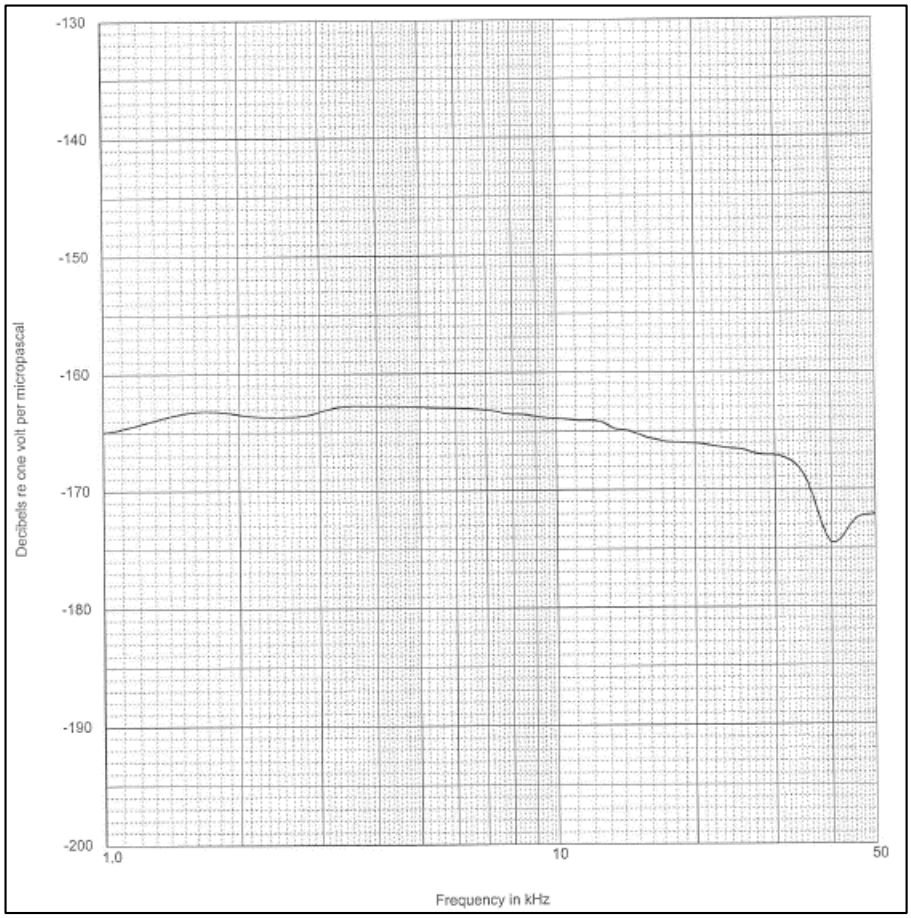

Figure 2-10. Frequency response of the HTI-96-MIN hydrophones

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 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 prior to the measurement program to ensure 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. Twice, 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 hostile. This system was exposed to strong currents also and the mooring failed during one of the deployments.

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 6 to 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. 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 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.

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NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

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[2] categorizes marine mammals into several 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

	Non-Impulse Sound (Vibratory Pile Driving)		Impulse Sound (Impact Pile Driving)		
			Level A Dual Criteria		
Species Hearing Group	Level A Weighted (dB SELcum)	Unweighted Level B (dB RMS)	(dB Peak)	Weighted (dB SELcum)	Unweighted Level B (dB RMS)
Low-Frequency Cetaceans (e.g., humpback whale)	199	120 or background	219	183	160
Mid-Frequency Cetaceans (e.g., beluga whale)	198		230	185	
High-Frequency Cetaceans (e.g., harbor porpoise)	173		202	155	
Phocids (e.g., harbor seal)	201		218	185	
Otariids (e.g., Steller sea lion)	219		232	203	

Note: All decibels (dB) are referenced to 1 microPascal (re: 1 µPa). Level A SELcum levels are weighted using auditory weighting filter shapes shown on Figure 3-1.

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 one-third 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

[2] NMFS. 2018. 2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. April.

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.

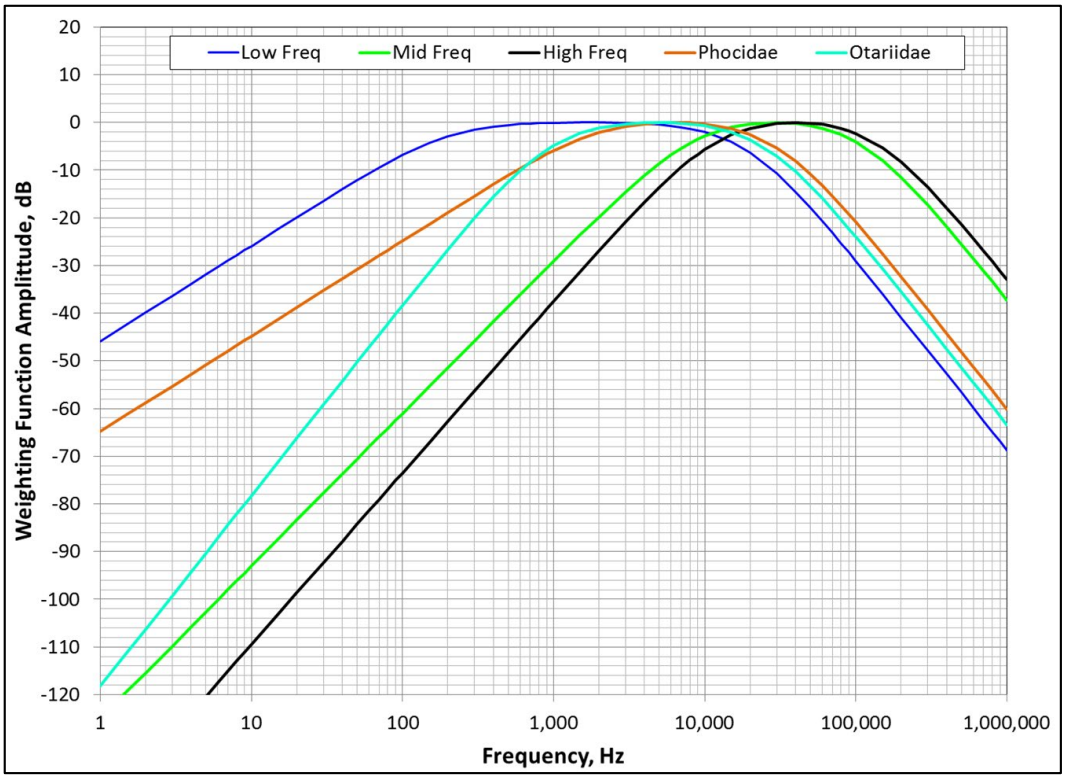


Figure 3-1. Marine mammal auditory weighting filter shapes from the 2018 NMFS Technical Guidance

3.2 Pile Driving and Acoustic Monitoring Events

3.2.1 Vibratory Pile Driving Events

Vibratory monitoring started on June 9, 2020, and was completed on June 25, 2020. Monitoring for vibratory pile driving was completed for ten 48-inch piles, two 36-inch piles, and seven 24-inch piles, though two piles were driven multiple times because they were affected by obstructions. Additionally, the installation of four air bubble casings and the removal of a 36-inch pin pile from the mud was also monitored.

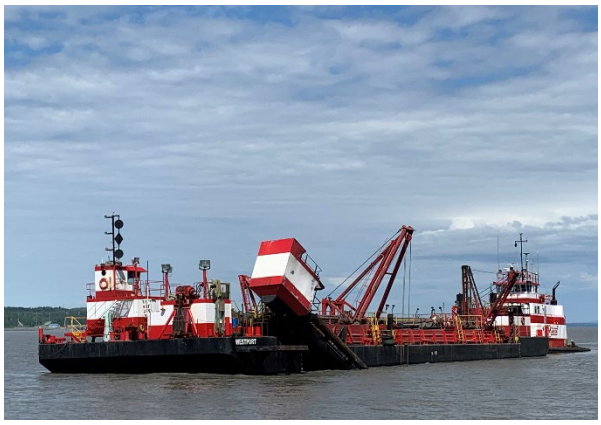
3.2.2 Impact Pile Driving Events

Impact pile driving monitoring started on June 10, 2020 and was completed on June 24, 2020. Monitoring of impact driving included eleven 48-inch piles. Two indicator piles were driven on multiple occasions to accommodate pile dynamic testing.

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 2016a). 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

During this survey, ambient levels were measured 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. Typically, background levels ranged from 120 to 130 dB at monitoring locations within approximately 200 meters of the pile driving activities. Background levels above 1,000 Hz are based on instrument background for the TC-4033 and TC-4013 hydrophones, which were mostly used at the close-in, SFD, and drift positions. However, a TC-4013 replaced the Loggerhead unit at the mooring position 1 location on June 20, 2020, after the Loggerhead unit was swept away on June 19, 2020.

At distances beyond 500 meters, background levels were about 115 to 125 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 positions on June 17, 2020. The close-in stations (i.e., those within 50 meters)

measured instrument background levels of about 110 to 120 dB at 1/3-octave band levels above 1,000 Hz, as these were less sensitive hydrophone systems used to measure the louder pile driving sounds.

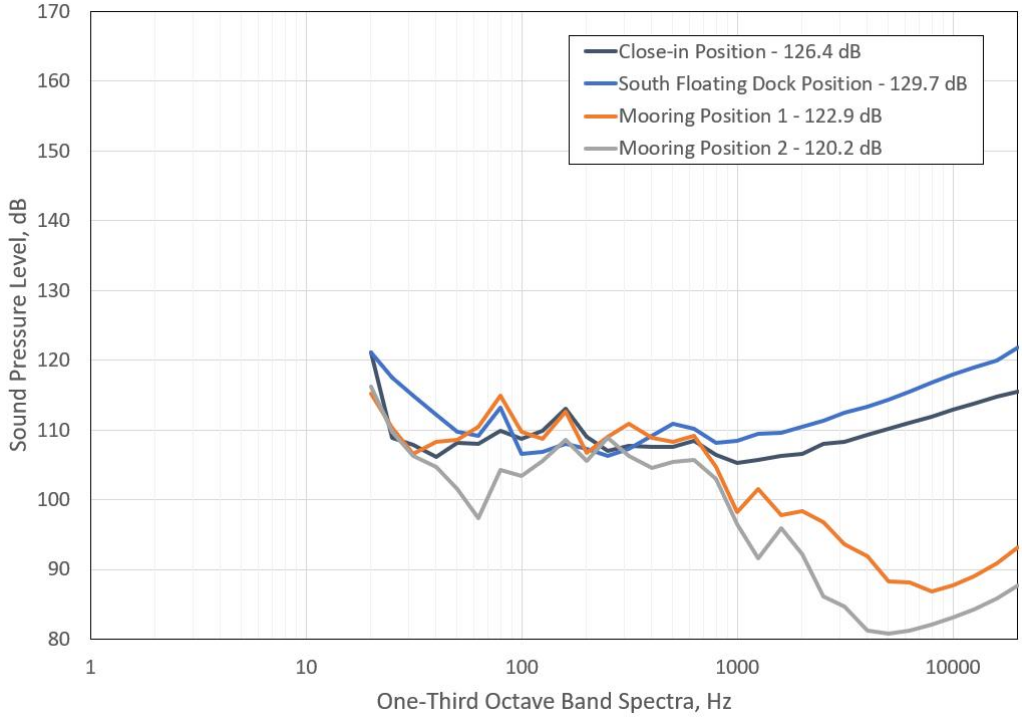


Figure 3-3. Sample of 1/3-octave band spectra for ambient sound pressure levels at each monitoring location

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.

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 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 measured prior to or just after vibratory pile installation. This was conducted by estimating the measured background sound level and logarithmically subtracting that level from the measured level during the pile driving event. The impact pile driving sounds were not affected by ambient sound conditions, as they were more than 10 dB above ambient or background levels.

NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

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 June 9, 2020, Pile Driving Activities

Hydroacoustic measurements were made during the vibratory installation of the Pile D-1 air bubble casing and Pile S-5, which was a 36-inch temporary trestle pile at Bent 3. The vibratory hammer used for both installations was an APE 300-6.

4.1.1 Vibratory Pile Driving Activities

Driving of the D-1 air bubble casing started at 3:28 p.m. and concluded at 3:47 p.m. The actual driving time was 8.3 minutes, and the water depth at the air bubble casing was 9 meters.

There were four measurement positions: at 27 meters (close-in), at 135 meters (SFD), at 690 meters (mooring 1), and at 2,335 meters (mooring 2). The water depth at the close-in and SFD positions was 17 meters, and the hydrophones were deployed approximately 6 meters below the water's surface. The water depth at each mooring position was 30 and 22 meters, respectively, and the hydrophones were bottom anchored at each of these locations, which means they were deployed 2 meters above the bottom.

Driving of Pile S-5 started at 4:00 p.m. and concluded 4:32 p.m., with 25.6 minutes of driving time, during low tide conditions in approximate 4 meters deep water with the air bubble casing operating. There were five monitoring positions: at 55 meters (close-in), at 145 meters (SFD), at 690 meters (mooring 1), at 2,335 meters (mooring 2), and at 638 meters (drift). The water depth at the close-in position was 12 meters, while the water depth at the SFD position was 10 meters. Hydrophones at both of these locations were deployed approximately 6 meters below the water's surface. The water depth at each mooring position was 25 and 17 meters, respectively, and the hydrophones were deployed 1 to 2 meters above the bottom. The water depth at the drift location was roughly 25 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.1.2 Impact Pile Driving Activities

No impact driving was conducted this day.

4.2 June 10, 2020, Pile Driving Activities

On June 10, 2020, hydroacoustic measurements were made during the vibratory installation of two 48-inch piles (A-1 and D-1), vibratory installation of three 24-inch piles (S-4, S-3, and S-1), and impact driving of two 48-inch piles (D-1 and A-1). The air bubble casing was operational during all pile driving activities. All vibratory driving was completed with the APE 300-6 hammer and impact driving was conducted with the Delmag D-180 hammer.

4.2.1 Vibratory Pile Driving Activities

Vibratory driving occurred between 8:51 a.m. and 8:57 a.m. for A-1 (total driving time of 4.7 minutes) in water depth of 18 meters. Measurements were conducted at four positions: at 12 meters (close-in), at 155 meters (SFD), at 545 meters (mooring 1), and at 2,355 meters (mooring 2). The water depth at the close-in and SFD positions was 18 meters, and the hydrophones were deployed approximately 6 meters below the water's surface. The water depths at each mooring position were 31 and 23 meters, respectively, and the hydrophones were deployed 2 meters above the bottom.

Vibratory driving occurred between 9:06 a.m. and 9:23 a.m. for S-4 (total driving time of 11.2 minutes) in water depth of 11 meters. Measurements were conducted at five positions: at 15 meters (trestle), at 55 meters (barge), at 140 meters (SFD), at 590 meters (mooring 1), and at 2,400 meters (mooring 2). The water depth at the trestle position was 15 meters, and the water depth at the barge and SFD positions was 19 meters. The hydrophone at trestle was deployed 2 meters above the seafloor, and hydrophones at both the barge and SFD locations were deployed approximately 6 meters below the water's surface. The water depths at each mooring position was 32 and 24 meters, respectively, and the hydrophones were deployed 2 meters above the bottom.

Vibratory driving occurred between 9:39 a.m. and 9:45 a.m. for D-1 (total driving time of 5 minutes) in water depth of 16 meters. Measurements were conducted at four positions: at 29 meters (close-in), at 155 meters (SFD), at 565 meters (mooring 1), and at 2,370 meters (mooring 2). The water depth at the close-in and SFD positions was 20 meters, and the hydrophones were deployed approximately 6 meters below the water's surface. The water depths at each mooring position was 33 and 25 meters, respectively, and the hydrophones were deployed 2 meters above the bottom.

Vibratory driving occurred between 10:37 a.m. and 10:49 a.m. for S-3 (total driving time of 11.8 minutes) in water depth of 12 meters. Measurements were conducted at five positions: at 11 meters (trestle), at 55 meters (barge), at 146 meters (SFD), at 590 meters (mooring 1), and at 2,400 meters (mooring 2). The water depth at the trestle position was 15 meters, and the water depth at the barge and SFD positions was 19 meters. The hydrophone at trestle was deployed 2 meters above the floor of the water, and hydrophones at both of the barge and SFD locations were deployed approximately 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 32 and 24 meters, respectively, and the hydrophones were deployed 2 meters above the bottom.

Vibratory driving occurred between 11:46 a.m. and 12:00 p.m. for S-1 (total driving time of 4.5 minutes) in water depth of 11 meters. Measurements were conducted at five positions: at 14 meters (trestle), at 58 meters (barge), at 157 meters (SFD), at 590 meters (mooring 1), and at 2,400 meters (mooring 2). The water depth at the trestle position was 16 meters, and the water depth at the barge and SFD positions was 20 meters. The hydrophone at trestle was deployed 2 meters above the floor of the water, and hydrophones at both of the barge and SFD locations were deployed approximately 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 33 and 25 meters, respectively, and the hydrophones were deployed 2 meters above the bottom.

4.2.2 Impact Pile Driving Activities

Impact driving occurred between 11:30 a.m. and 11:56 a.m. for D-1 (total of 950 strikes) in water depth of 16 meters. Measurements were conducted at four positions: at 29 meters (close-in), at 155 meters (SFD), at 565 meters (mooring 1), and at 2,370 meters (mooring 2). The water depth at the close-in and SFD positions was 20 meters. The close-in hydrophone was deployed approximately 6 meters below the water's surface, and the SFD hydrophone was deployed 2 meters above the bottom. The water depths at the

mooring 1 and 2 positions were 33 and 25 meters, respectively, and both hydrophones were bottom-anchored.

Impact driving occurred between 2:35 p.m. and 3:34 p.m. for A-1 (total of 1,021 strikes) in water depth of 14 meters. Measurements were conducted at five locations: at 12 meters (close-in), at 155 meters (SFD), at 545 meters (mooring 1), at 4,050 meters (mooring 2), and at drift distances of 2,025 meters from 2:37 p.m. to 2:40 p.m. and 2,783 meters from 3:17 p.m. to 3:27 p.m. The water depth at the close-in and SFD positions was 16 meters. The close-in hydrophone was deployed approximately 6 meters below the water's surface, and the SFD hydrophone was deployed 2 meters above the bottom. The water depths at the mooring 1 and 2 positions were 29 and 21 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location ranged from 17 to 19 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.3 June 12, 2020, Pile Driving Activities

Hydroacoustic measurements on June 12, 2020, were made during the vibratory and impact installation of two 48-inch piles (E-1 and B-2). Impact driving of Pile B-2 was only partially completed on this day. Two 24-inch trestle piles (T-13 and T-14) were also installed with a vibratory hammer. The air bubble casing was operational during all pile driving activities. All driving was completed with the APE 300-6 hammer or Delmag D-180 hammer.

4.3.1 Vibratory Pile Driving Activities

Vibratory driving for E-1 occurred between 10:28 a.m. and 10:34 a.m. (total driving time of 5.2 minutes) in water depth of 12 meters. Measurements were conducted at five positions during the vibratory driving: at 34 meters (close-in), at 150 meters (SFD), at 798 meters (mooring 1), at 2,584 meters (mooring 2), and at 312 meters (drifting vessel). The water depth at the close-in and SFD positions was 18 meters, and the hydrophones were deployed approximately 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 36 and 21 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth measured during the drift was approximately 20 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

Vibratory driving for B-2 occurred between 4:11 p.m. and 4:16 p.m. (total driving time of 4 minutes) in water depth of 14 meters. Measurements were conducted at five positions during the vibratory driving: at 18 meters (close-in), at 152 meters (SFD), at 781 meters (mooring 1), at 2,568 meters (mooring 2), and at 1,438 meters (drifting vessel). The water depth at the close-in and SFD positions was 16 meters, and the hydrophones were deployed approximately 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were34 and 19 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth measured during the drift was approximately 26 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

Vibratory driving for T-13 occurred between 5:35 p.m. and 5:56 p.m. (total driving time of 19.2 minutes) in water depth of 8 meters. Measurements were conducted at four positions during the vibratory driving: at 5 meters (close-in), at 144 meters (SFD), at 824 meters (mooring 1), and at 2,608 meters (mooring 2). The water depth at the close-in position was 12 meters, and the hydrophone was deployed 2 meters above the bottom. At the SFD position, water depth was 14 meters, and the hydrophone was deployed approximately 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 32 and 17 meters, respectively, and the hydrophones were deployed 2 meters above the bottom.

Vibratory driving for T-14 occurred between 6:37 p.m. and 7:06 p.m. (total driving time of 21.3 minutes) in water depth of 5 meters. Measurements were conducted at four positions during the vibratory driving: at 18 meters (close-in), at 131 meters (SFD), at 827 meters (mooring 1), and at 2,606 meters (mooring 2). The water depth at the close-in position was 11 meters, and the hydrophone was deployed 2 meters above the bottom. At the SFD position, water depth was 13 meters, and the hydrophone was deployed approximately 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 31 and 16 meters, respectively, and the hydrophones were deployed 2 meters above the bottom.

4.3.2 Impact Pile Driving Activities

Impact driving occurred between 11:33 a.m. and 12:04 p.m. for E-1 (total of 1,101 strikes) in water depth of 13 meters. Measurements were conducted at five positions during the impact driving: at 34 meters (close-in), at 150 meters (SFD), at 798 meters (mooring 1), at 2,584 meters (mooring 2), and at drift distances of 1,161 meters from 11:37 a.m. to 11:51 a.m. and 1,636 meters from 11:56 a.m. to 12:04 p.m. The water depth at the close-in and SFD positions was 19 meters, and the hydrophones were deployed 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 37 and 22 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location ranged from 26 to 28 meters, with the hydrophone deployed approximately 10 meters below the surface.

The partial installation of Pile B-2 started at 4:42 p.m. and concluded at 4:51 p.m. (total of 231 strikes) in water depth of 13 meters. Measurements were conducted at five positions during the partial impact driving: at 18 meters (close-in), at 152 meters (SFD), at 781 meters (mooring 1), at 2,568 meters (mooring 2), and at 1,778 meters (drifting vessel). The water depth at the close-in and SFD positions was 15 meters, and the hydrophones were deployed 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 33 and 18 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location was 23 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.4 June 14, 2020, Pile Driving Activities

Hydroacoustic measurements on June 14, 2020, were made during the vibratory and impact installation of one 48-inch permanent trestle pile (HT-2) and one 48-inch permanent platform pile (C-2). The air bubble casing was operational during all pile driving activities. Vibratory installation of two air bubble casings (C-2 and A-2) was also completed on June 14, 2020. Vibratory driving for both 48-inch piles was completed with the APE 300-6 hammer. An ICE 44-B vibratory hammer was used for the installation of both air bubble casings. The Delmag D-180 hammer was used for impact driving.

4.4.1 Vibratory Pile Driving Activities

Vibratory driving occurred between 11:12 a.m. and 11:21 a.m. for the C-2 air bubble casing (total driving time of 7.8 minutes) in water depth of 12 meters. Measurements were conducted at four positions during the vibratory driving: at 12 meters (platform), at 23 meters (barge), at 144 meters (SFD), and at 2,611 meters (mooring 2). Due to strong currents, pile driving could not be measured over ambient levels at the mooring 1 position. The water depth at the platform, barge, and SFD positions was 15 meters. The hydrophone at the platform position was deployed 2 meters above the bottom, while the hydrophones at the barge and SFD positions were deployed approximately 6 meters below the water's surface. The water depth at the mooring 2 position was 14 meters, and the hydrophone was deployed 2 meters above the bottom.

Vibratory driving occurred between 1:27 p.m. and 1:36 p.m. for HT-2 (total driving time of 9.2 minutes) in water depth of 10 meters. Measurements were conducted at five positions during the vibratory driving: at 12 meters (trestle), at 50 meters (platform), at 137 meters (SFD), at 2,650 meters (mooring 2), and at 910 meters (drifting vessel). Due to strong currents, pile driving could not be determined over ambient levels at the mooring 1 position. The water depth at the trestle position was 15 meters, and the hydrophone was deployed 3 meters above the bottom. At the platform and SFD positions, the water depth was 19 meters. The hydrophone at the platform position was deployed 2 meters above the bottom, and at the SFD position, the hydrophone was deployed approximately 6 meters below the water's surface. The water depth at the mooring 2 position was 18 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth measured during the drift was approximately 27 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

Vibratory driving occurred between 1:54 p.m. and 2:06 p.m. for C-2 (total driving time of 10 minutes) in water depth of 16 meters. Measurements were conducted at six positions during the vibratory driving: at 12 meters (platform), at 23 meters (barge), at 144 meters (SFD), at 789 meters (mooring 1), at 2,611 meters (mooring 2), and at drift distances of 544 meters from 1:54 p.m. to 1:56 p.m. and 480 meters from 2:03 p.m. to 2:06 p.m. The water depth at the platform, barge, and SFD positions was 19 meters. The hydrophone at the platform position was deployed 2 meters above the bottom, while the hydrophones at the barge and SFD positions were deployed approximately 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 31 and 18 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth measured during the drift was approximately 27 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

Vibratory driving occurred between 4:06 p.m. and 4:13 p.m. for the A-2 air bubble casing (total driving time of 3.9 minutes) in water depth of 18 meters. Measurements were conducted at three positions during the vibratory driving: at 13 meters (close-in), at 146 meters (SFD), and at 777 meters (mooring 1). The mooring 2 position was retrieved prior to this installation. The water depth at the close-in and SFD positions was 19 meters, and the hydrophones were deployed 6 meters below the water's surface. The water depth at the mooring 1 position was 31 meters, and the hydrophone was deployed 2 meters above the bottom.

4.4.2 Impact Pile Driving Activities

Impact driving occurred between 2:18 p.m. and 2:41 p.m. for HT-2 (total of 990 strikes) in water depth of 10 meters. Measurements were conducted at six positions during the impact driving: at 12 meters (trestle), at 50 meters (platform), at 137 meters (SFD), at 827 meters (mooring 1), at 2,650 meters (mooring 2), and at drift distances of 1,781 meters from 2:20 p.m. to 2:23 p.m. and 1,630 meters from 2:24 p.m. to 2:27 p.m. The water depth at the trestle, platform, and SFD positions was 19 meters. The hydrophones at the trestle and platform were deployed 2 meters above the bottom, and the hydrophone at the SFD position was deployed 6 meters below the water's surface. The water depths at mooring 1 and 2 positions 1 were 31 and 18 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location was 30 meters, with the hydrophone deployed approximately 10 meters below the surface.

The impact installation of Pile C-2 started at 4:41 p.m. and concluded at 5:05 p.m. (total of 936 strikes) in water depth of 15 meters. Measurements were conducted at five positions during the impact driving: at 12 meters (platform), at 23 meters (barge), at 144 meters (SFD), at 793 meters (mooring 1), and at drift distances of 1,014 meters from 4:53 p.m. to 4:57 p.m. and 1,110 meters from 4:58 p.m. to 5:02 p.m. The mooring 2 position was retrieved prior to this installation. The water depth at the platform, barge, and SFD positions was 18 meters. The hydrophone at the platform position was deployed 2 meters above the

bottom, and the hydrophones at the barge and SFD positions were deployed 6 meters below the water's surface. The water depth at the mooring 1 position was 30 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the drift location was 27 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.5 June 16, 2020, Pile Driving Activities

Hydroacoustic measurements on June 16, 2020, were made during the vibratory installation of two 24-inch temporary trestle piles (T-15 and T-16), one 48-inch permanent platform pile (B-1), and one 36-inch temporary trestle pile from Bent 2 (S-5). Impact installation was completed for two 48-inch permanent platform piles (B-1 and B-2). The air bubble casing was operational during the installation of all three temporary piles and during the impact driving of Pile B-2. Pile B-1, which was suspected to have run into an obstruction, was vibrated without an air bubble casing and was then impact driven with the air bubble casing. A special guide, which would not accommodate the air bubble casing, had to be used for this pile. This guide may have caused elevated sounds at the beginning of the driving event as the pile would wobble and make contact with the guide until it became stable.

4.5.1 Vibratory Pile Driving Activities

Vibratory driving for both 24-inch piles (T-15 and T-16) was completed with the APE 200-6 hammer. An APE 300-6 vibratory hammer was used for the installation of Piles B-1 and S-5.

Vibratory driving occurred between 8:31 a.m. and 8:58 a.m. for Pile T-15 (total driving time of 25.6 minutes) in water depth of 10 meters. Measurements were conducted at four positions during the vibratory driving: at 29 meters (trestle), at 48 meters (barge), at 127 meters (SFD), at 2,620 meters (mooring 2), and at 263 meters (drifting vessel). Due to strong currents, pile driving could not be determined over ambient levels at the mooring 1 position. The water depth at the trestle position was 11 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the barge and SFD positions was 15 meters, and the hydrophones were deployed 6 meters below the water's surface. The water depth at the mooring 2 position was 16 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth measured during the drift was approximately 20 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

Vibratory driving occurred between 9:58 a.m. and 10:18 a.m. for Pile T-16 (total driving time of 24 minutes) in water depth of 7 meters. Measurements were conducted at four positions during the vibratory driving: at 41 meters (trestle), at 52 meters (barge), at 141 meters (SFD), and at 2,618 meters (mooring 2). The water depth at the trestle position was 9 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the barge and SFD positions was 13 meters, and the hydrophones were deployed 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 26 and 14 meters, respectively, and the hydrophone was deployed 2 meters above the bottom.

Vibratory driving occurred between 2:28 p.m. and 2:46 p.m. for Pile B-1 (total driving time of 15 minutes) in water depth of 14 meters. Measurements were conducted at five positions during the vibratory driving: at 16 meters (barge), at 53 meters (trestle), at 151 meters (SFD), at 2,588 meters (mooring 2), and at 716 meters (drifting vessel). Due to strong currents, pile driving could not be determined over ambient levels at the mooring 1 position. The water depth at the trestle position was 15 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the barge and SFD positions was 19 meters, and the hydrophones were deployed 6 meters below the water's surface. The water depth at the mooring 2 position was 20 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth

measured during the drift was approximately 26 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

Vibratory driving occurred between 4:47 p.m. and 5:28 p.m. for Pile S-5 (total driving time of 36.4 minutes) in water depth of 13 meters. Measurements were conducted at six positions during the vibratory driving: at 31 meters (trestle), at 44 meters (barge), at 143 meters (SFD), at 815 meters (mooring 1), at 2,616 meters (mooring 2), and at 514 meters (drift vessel). The water depth at the trestle position was 15 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the barge and SFD positions was 17 meters, and the hydrophones were deployed 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 32 and 20 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location was 27 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.5.2 Impact Pile Driving Activities

All impact driving was completed with the Delmag D-180 hammer.

Impact driving occurred between 9:18 a.m. and 9:42 a.m. for B-2 (total of 757 strikes) in water depth of 13 meters. Measurements were conducted at five positions during the impact driving: at 15 meters (close-in), at 146 meters (SFD), at 788 meters (mooring 1), at 2,586 meters (mooring 2), and at 1,503 meters (drifting vessel). The water depth at the close-in and SFD positions was 14 meters, and the hydrophones were deployed approximately 6 meters below the water's surface. The water depths at each mooring position were 27 and 15 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth measured during the drift was approximately 25 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

The impact installation of Pile B-1 started at 4:19 p.m. and concluded at 4:46 p.m. (total of 969 strikes) in water depth of 17 meters. There were five monitoring positions during the impact driving: at 16 meters (close-in), at 151 meters (SFD), at 787 meters (mooring 1), at 2,588 meters (mooring 2), and at 1,544 meters (drifting vessel). The water depth at the close-in and SFD positions was 19 meters, and the hydrophones were deployed approximately 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 32 and 20 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth measured during the drift was approximately 27 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

4.6 June 17, 2020, Pile Driving Activities

Hydroacoustic measurements on June 17, 2020, were made during the vibratory installation of one 36-inch temporary trestle pile from Bent 2 (S-2) and one 24-inch temporary trestle pile (S-1). The air bubble casing was operational during the installation of both temporary piles.

4.6.1 Vibratory Pile Driving Activities

Vibratory driving was completed with the APE 300-6 hammer.

Vibratory driving occurred between 1:21 p.m. and 2:01 p.m. for Pile S-2 (total driving time of 36 minutes) in water depth of 7 meters. Measurements were conducted at five positions during the vibratory driving: at 25 meters (trestle), at 154 meters (SFD), at 807 meters (mooring 1), at 2,623 meters (mooring 2), and at 335 meters (drifting vessel). The water depth at the trestle position was 9 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the SFD position was 11 meters, and the hydrophone was deployed 6 meters below the water's surface. The water depths at the mooring 1 and 2

positions were 25 and 14 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location was 20 meters, with the hydrophone deployed approximately 10 meters below the surface.

Vibratory driving occurred between 4:01 p.m. and 4:14 p.m. for Pile S-1 (total driving time of 10.8 minutes) in water depth of 11 meters. Measurements were conducted at five positions during the vibratory driving: at 25 meters (trestle), at 157 meters (SFD), at 807 meters (mooring 1), at 2,623 meters (mooring 2), and at 475 meters (drifting vessel). The water depth at the trestle position was 14 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the SFD position was 16 meters, and the hydrophone was deployed 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 30 and 19 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location was 25 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.6.2 Impact Pile Driving Activities

No impact driving was conducted this day.

4.7 June 19, 2020, Pile Driving Activities

Hydroacoustic measurements on June 19, 2020, were made during the vibratory and impact installation of one 48-inch permanent platform pile (E-4). The air bubble casing was operational during all pile driving. Vibratory driving was completed with the APE 300-6 vibratory hammer. Impact driving was completed with the Delmag D-180 hammer.

4.7.1 Vibratory Pile Driving Activities

Vibratory driving occurred between 12:27 p.m. and 12:44 p.m. (total driving time of 10.1 minutes) in water depth of 7 meters. Measurements were conducted at six positions during the vibratory driving: at 15 meters (platform), at 38 meters (barge), at 132 meters (SFD), at 810 meters (mooring 1), at 2,595 meters (mooring 2), and at 461 meters (drift vessel). The water depth at the platform, barge, and SFD positions was 12 meters. At the platform position, the hydrophone was deployed 2 meters above the bottom, and the hydrophones at the barge and SFD positions were deployed 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 25 and 13 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location was 20 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.7.2 Impact Pile Driving Activities

Impact driving occurred between 3:28 p.m. and 4:00 p.m. (total of 1,211 strikes) in water depth of 9 meters. Measurements were conducted at six positions during the impact driving: at 15 meters (platform), at 38 meters (barge), at 132 meters (SFD), at 810 meters (mooring 1), at 2,595 meters (mooring 2), and at drift distances of 1,247 meters from 3:33 p.m. to 3:43 p.m. and 818 meters from 3:52 p.m. to 4:00 p.m. The water depth at the platform, barge, and SFD positions was 14 meters. The hydrophone at the platform was deployed 2 meters above the bottom, and the hydrophones at the barge and SFD positions were deployed 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 27 and 15 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location ranged from 27 to 28 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.8 June 20, 2020, Pile Driving Activities

Hydroacoustic measurements on June 20, 2020, were made during the vibratory and impact installation of one 48-inch access trestle pile (GT-3). The air bubble casing was operational during these pile driving activities. Vibratory installation of two air bubble casing casings (D-5 and E-5) was also completed on June 20, 2020.

4.8.1 Vibratory Pile Driving Activities

Vibratory driving for the 48-inch pile was completed with the APE 300-6 hammer. An ICE 44-B vibratory hammer was used for the installation of both air bubble casings.

Vibratory driving occurred between 2:28 p.m. and 2:40 p.m. for Pile GT-3 (total driving time of 7.7 minutes) in water depth of 5 meters. Measurements were conducted at five positions during the vibratory driving: at 17 meters (trestle), at 55 meters (barge), at 148 meters (SFD), at 2,616 meters (mooring 2), and at 339 meters (drifting vessel). The mooring 1 monitoring system was lost on this day; so, data could not be retrieved at this location. The water depth at the trestle position was 10 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the barge position was 12 meters, and the water depth at the SFD position was 18 meters. The hydrophones at the barge and SFD positions were deployed approximately 6 meters below the water's surface. The water depth at the mooring 2 position was 18 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth measured during the drift was approximately 15 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

Vibratory driving occurred between 4:09 p.m. and 4:12 p.m. for the D-5 air bubble casing (total driving time of 3.1 minutes) in water depth of 10 meters. Measurements were conducted at three positions during the vibratory driving: at 14 meters (close-in), at 118 meters (SFD), and at 2,596 meters (mooring 2). The mooring 1 monitoring system was lost on this day; so, data could not be retrieved at this location. The water depth at the close-in position was 14 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the SFD position was 20 meters, and the hydrophone was deployed approximately 6 meters below the water's surface. The water depth at the mooring 2 position was 20 meters, and the hydrophone was deployed 2 meters above the bottom.

Vibratory driving occurred between 4:22 p.m. and 4:25 p.m. for the E-5 air bubble casing (total driving time of 0.6 minutes) in water depth of 10 meters. Measurements were conducted at three positions during the vibratory driving: at 20 meters (close-in), at 121 meters (SFD), and at 2,601 meters (mooring 2). The mooring 1 monitoring system was lost on this day; so, data could not be retrieved at this location. The water depth at the close-in position was 14 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the SFD position was 20 meters, and the hydrophone was deployed approximately 6 meters below the water's surface. The water depth at the mooring 2 position was 20 meters, and the hydrophone was deployed 2 meters above the bottom.

4.8.2 Impact Pile Driving Activities

Impact driving was completed with the Delmag D-180 hammer between 3:32 p.m. and 4:00 p.m. for GT-3 (total of 968 strikes) in water depth of 6 meters. There were four monitoring positions: at 17 meters (close-in), at 148 meters (SFD), at 2,616 meters (mooring 2), and at drift distances of 1,421 meters from 3:34 p.m. to 3:46 p.m. and 1,655 meters from 3:55 p.m. to 4:00 p.m. The mooring 1 monitoring system was lost on this day; so, data were not retrieved. The water depth at the close-in position was 12 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the SFD position was 20 meters, and the hydrophone was deployed 6 meters below the water's surface. The water depth at the mooring 2

position was 20 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the drift location was 23 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.9 June 23, 2020, Pile Driving Activities

Hydroacoustic measurements on June 23, 2020, were made during the vibratory and impact installation of one 48-inch permanent platform pile (B-5). The air bubble casing was operational during all pile driving. Vibratory driving was completed with the APE 300-6 vibratory hammer. Impact driving was completed with the Delmag D-180 hammer.

4.9.1 Vibratory Pile Driving Activities

Vibratory driving occurred between 8:32 a.m. and 8:44 a.m. (total driving time of 9.8 minutes) in water depth of 19 meters. Measurements were conducted at three positions during the vibratory driving: at 15 meters (close-in), at 125 meters (SFD), and at 800 meters (mooring 1). The water depth at the close-in and SFD positions was 21 meters. At the close-in position, the hydrophone was deployed 6 meters below the water's surface, while the hydrophone at the SFD position was deployed 2 meters above the bottom. The water depth at the mooring 1 position was 37 meters, and the hydrophone was deployed 2 meters above the bottom.

4.9.2 Impact Pile Driving Activities

Impact driving occurred between 9:43 a.m. and 10:18 a.m. (total of 1,394 strikes) in water depth of 18 meters. Measurements were conducted at five positions during the impact driving: at 15 meters (close-in), at 125 meters (SFD), at 800 meters (mooring 1), at 2,600 meters (mooring 2), and at 1,624 meters (drifting vessel). The water depth at the close-in and SFD positions was 20 meters. The hydrophone at the close-in position was deployed 2 meters above the bottom, and the hydrophone at the SFD positions was deployed 6 meters below the water's surface. The water depths at the mooring 1 and 2 positions were 36 and 18 meters, respectively, and the hydrophones were deployed 2 meters above the bottom. The water depth at the drift location was 30 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.10 June 24, 2020, Pile Driving Activities

Hydroacoustic measurements on June 24, 2020, were made during the vibratory installation of three 24-inch temporary trestle piles (S-4, S-3, and S-1), one 36-inch temporary trestle pile (S-5) located along Bent 1, and one 48-inch permanent pile (B-4), as well as the vibratory removal of a 36-inch pin pile. Additionally, monitoring was completed during the impact installation of one 48-inch permanent pile (D-5) and the restrike of the 48-inch A-1 pile. The air bubble casing was operational during all pile driving activities. Vibratory driving and vibratory removal for all 24-, 36-, and 48-inch piles was completed with the APE 300-6 hammer. Impact driving was completed with the Delmag D-180 hammer. Strong current and two- to three-foot seas caused high background sounds. Mooring 1 positioned could not be adequately deployed due to strong tidal currents.

4.10.1 Vibratory Pile Driving Activities

Vibratory driving occurred between 2:30 p.m. and 2:37 p.m. for Pile S-3 (total driving time of 7.8 minutes) in water depth of 9 meters. Measurements were conducted at four positions during the vibratory driving: at 13 meters (close-in), at 150 meters (SFD), and at 2,620 meters (mooring 2). The water depth at the close-

in and SFD positions was 14 meters. The hydrophone at the close-in position was deployed 2 meters above the bottom, while the hydrophone at the SFD position was deployed 6 meters below the water's surface. The water depth at the mooring 2 position was 20 meters, and the hydrophone was deployed 2 meters above the bottom.

Vibratory driving occurred between 3:25 p.m. and 3:35 p.m. for Pile S-1 (total driving time of 9.6 minutes) in water depth of 8 meters. Measurements were conducted at four positions during the vibratory driving: at 16 meters (close-in), at 159 meters (SFD), at 2,620 meters (mooring 2), and at 553 meters (drifting vessel). The water depth at the close-in and SFD positions was 13 meters. The hydrophone at the close-in position was deployed 2 meters above the bottom, while the hydrophone at the SFD position was deployed 6 meters below the water's surface. The water depth at the mooring 2 position was 19 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth measured during the drift was approximately 20 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

Removal of a 36-inch-diameter pin pile in very shallow water or tidal mud with a vibratory driver was measured between 4:16 p.m. and 4:52 p.m. (total driving time of 33.4 minutes). Measurements were conducted at three positions during pile removal: at 9 meters (close-in), at 141 meters (SFD), and at 2,635 meters (mooring 2). The water depth at the close-in and SFD positions was 12 meters. The hydrophone at the close-in position was deployed 2 meters above the bottom, while the hydrophone at the SFD position was deployed 6 meters below the water's surface. The water depth at the mooring 2 position was 18 meters, and the hydrophone was deployed 2 meters above the bottom.

Vibratory driving occurred between 4:47 p.m. and 4:59 p.m. for Pile B-4 (total driving time of 8 minutes) in water depth of 10 meters. Measurements were conducted at three positions during the vibratory driving: at 40 meters (close-in), at 133 meters (SFD), and at 2,605 meters (mooring 2). The water depth at the close-in and SFD positions was 12 meters. The hydrophone at the close-in position was deployed 2 meters above the bottom, while the hydrophone at the SFD position was deployed 6 meters below the water's surface. The water depth at the mooring 2 position was 18 meters, and the hydrophone was deployed 2 meters above the bottom.

Vibratory driving occurred between 5:06 p.m. and 5:37 p.m. for Pile S-5 (total driving time of 31.5 minutes) in water depth of 6 meters. Measurements were conducted at four positions during the vibratory driving: at 14 meters (close-in), at 143 meters (SFD), at 2,615 meters (mooring 2), and at 205 meters (drifting vessel). The water depth at the close-in and SFD positions was 12 meters. The hydrophone at the close-in position was deployed 2 meters above the bottom, while the hydrophone at the SFD position was deployed 6 meters below the water's surface. The water depth at the mooring 2 position was 18 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth measured during the drift was approximately 14 meters at the vessel, and the hydrophone was deployed 10 meters below the water's surface.

4.10.2 Impact Pile Driving Activities

Impact driving of Pile D-5 occurred between 10:35 a.m. and 11:03 a.m. (total of 1,133 strikes) in water depth of 16 meters. Measurements were conducted at four positions during the impact driving: at 35 meters (close-in), at 125 meters (SFD), at 2,620 meters (mooring 2), and at drift distances of 800 meters from 10:35 a.m. to 10:54 a.m. and 1,129 meters from 10:55 a.m. to 11:03 a.m. Equipment at the mooring 1 position turned off during driving, and data from this location were not available for analysis. The water depth at the close-in and SFD positions was 20 meters. The hydrophone at the close-in position was deployed 2 meters above the bottom, while the hydrophone at the SFD position was deployed 6 meters below the water's surface. The water depth at the mooring 2 position was 26 meters, and the hydrophone

was deployed 2 meters above the bottom. The water depth at the drift location was 29 meters, with the hydrophone deployed approximately 10 meters below the surface.

The restrike of Pile A-1 occurred between 2:46 p.m. and 2:56 p.m. (total of 278 strikes) in water depth of 13 meters. There were four measurements positions: at 40 meters (close-in), at 152 meters (SFD), at 2,600 meters (mooring 2), and at 1,459 meters (drifting vessel). Equipment at the mooring 1 position turned off during driving, and data from this location were not available for analysis. The water depth at the close-in and SFD positions was 13 meters. The hydrophone at the close-in position was deployed 2 meters above the bottom, while the hydrophone at the SFD position was deployed 6 meters below the water's surface. The water depth at the mooring 2 position was 19 meters, and the hydrophone was deployed 2 meters above the bottom. The water depth at the drift location was 24 meters, with the hydrophone deployed approximately 10 meters below the surface.

4.11 June 25, 2020, Pile Driving Activities

Hydroacoustic measurements on June 25, 2020, were made only during the vibratory installation of one 36-inch temporary trestle pile at Bent 1 (S-2). The air bubble casing was operational during all pile driving. Vibratory driving was completed with the APE 300-6 vibratory hammer.

4.11.1 Vibratory Pile Driving Activities

Vibratory driving occurred between 12:23 p.m. and 12:45 p.m. (total driving time of 22.1 minutes) in water depth of 14 meters. Measurements were conducted at three positions during the vibratory driving: at 10 meters (close-in), at 155 meters (SFD 1), and at 190 meters (SFD 2). The water depth at the close-in position was 14 meters, and the hydrophone was deployed 6 meters below the water's surface. The water depth at both SFD positions was 19 meters, and the hydrophones were deployed 6 meters below the water's surface.

4.11.2 Impact Pile Driving Activities

No impact driving was conducted this day.

NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

5. Measurement Results

Full summary tables showing each measured sound level metric, hammer used, and water depths is provided in Appendix A for vibratory driving and in Appendix B for impact driving. Appendix C provides the frequency spectrographs for selected positions used to develop source levels and transmission loss coefficients. All results summarized in this chapter include peak levels and RMS levels for vibratory driving, and peak, 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 Vibratory Pile Installation with Air Bubble Casing

5.1.1 June 9, 2020, 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 the Pile S-5. Also shown in the figure are the RMS time histories for each monitoring location. The time histories for the stationary monitoring locations show the period of overlap for the drifting vessel. Table 5-1summarizes the ambient sound level (labeled as “Background”), measured sound level (labeled as “Measured”), and the RMS levels minus the background level (labeled as “Project”) for Pile S-5 in the east-west monitoring line, which includes the near field monitoring locations and the distant mooring positions. Table 5-2 summarizes the monitoring positions in the north direction, which includes the nearest position and the SFD position. While the close-in and both very far-field mooring positions fell in a relatively straight line, in mostly an east-west direction from the pile (across Knik Arm), the SFD monitoring location was to the north, in an orthogonal direction. Further, the spectra for the SFD position during the driving of multiple piles throughout June 2020 showed unusual behavior compared to the other monitoring positions. Figure 5-1 shows this in the frequency bands above 800 Hz. Therefore, the data collected at the SFD position were excluded from transmission loss calculations. Table 5-1 also includes the transmission loss coefficients calculated for the pile driving event on June 9, 2020, with and without the drifting vessel for Pile S-5. Full summary tables showing each measured metric, hammer used, and water depths is provided in Appendix A. Figures and tables presenting this information for other days are also presented in this section.

For all 24-, 36-, and 48-inch pile installations summarized in this section, the air bubble casing was used. The exception was Pile B-1 (48-inch) installed on June 16, 2020. Pile B-1 was unattenuated and is identified as such in this section. In addition, the installation of the air bubble casings was unattenuated.

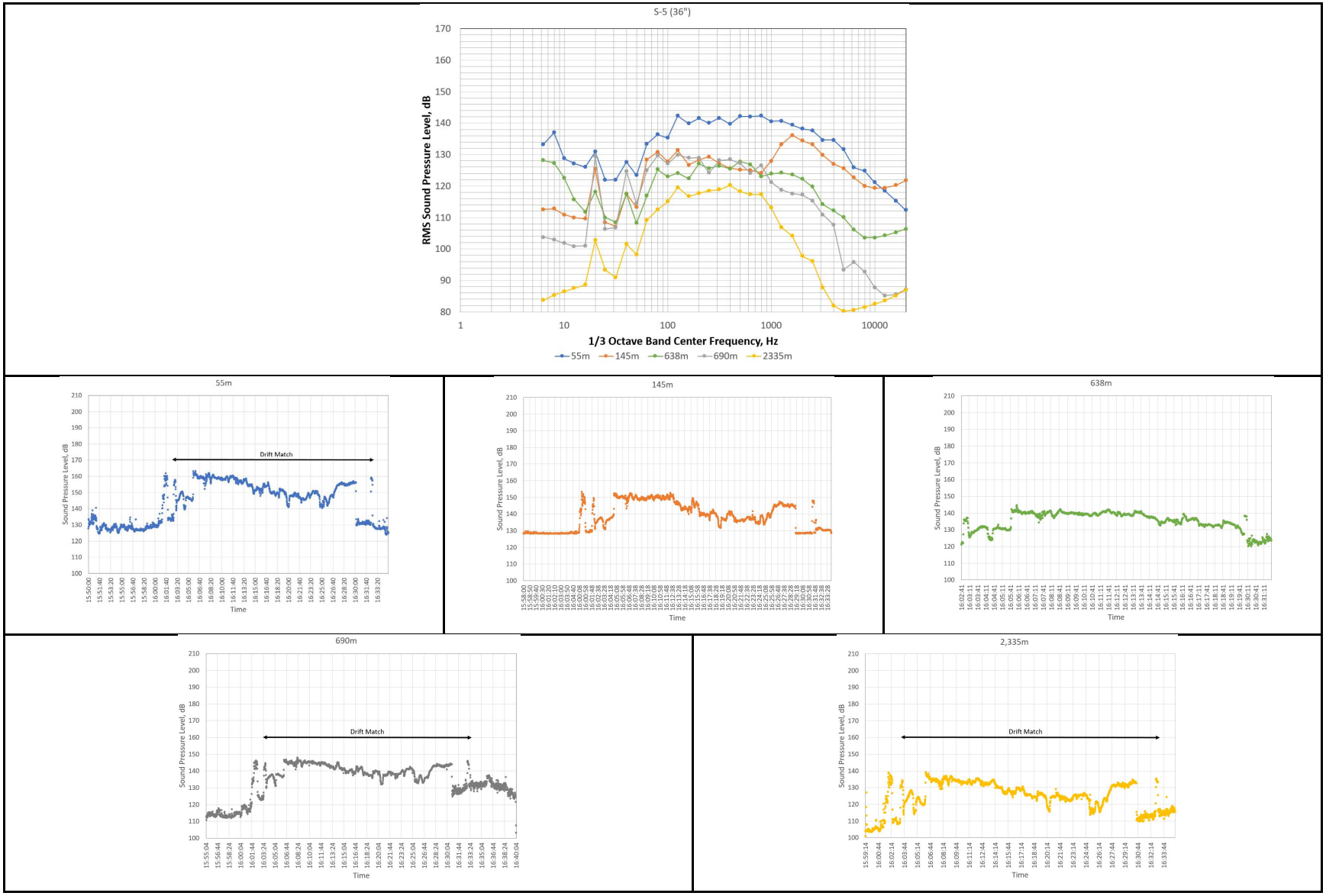


Figure 5-1. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 9, 2020 (Pile S-5)

Table 5-1. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 9, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project[a]	TL Coefficients	Level at 10 meters
16:00 to 16:29	S-5 (36-inch, Bent 3)	55	130	154	154	14.9	165.9	130	154	154	14.9	165.9
		638	N/A					125	139	139		
		690	130	141	141			130	141	141		
		2,335	115	130	130			115	130	130		

[a]Project = Measured - Background

Table 5-2. Summary of RMS data in the north direction for piles driven on June 9, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project[a]
16:00 to 16:29	S-5 (36-inch, Bent 3)	55	130	154	154
		145	130	145	145

[a]Project = Measured - Background

5.1.2 June 10, 2020, Measurement Results

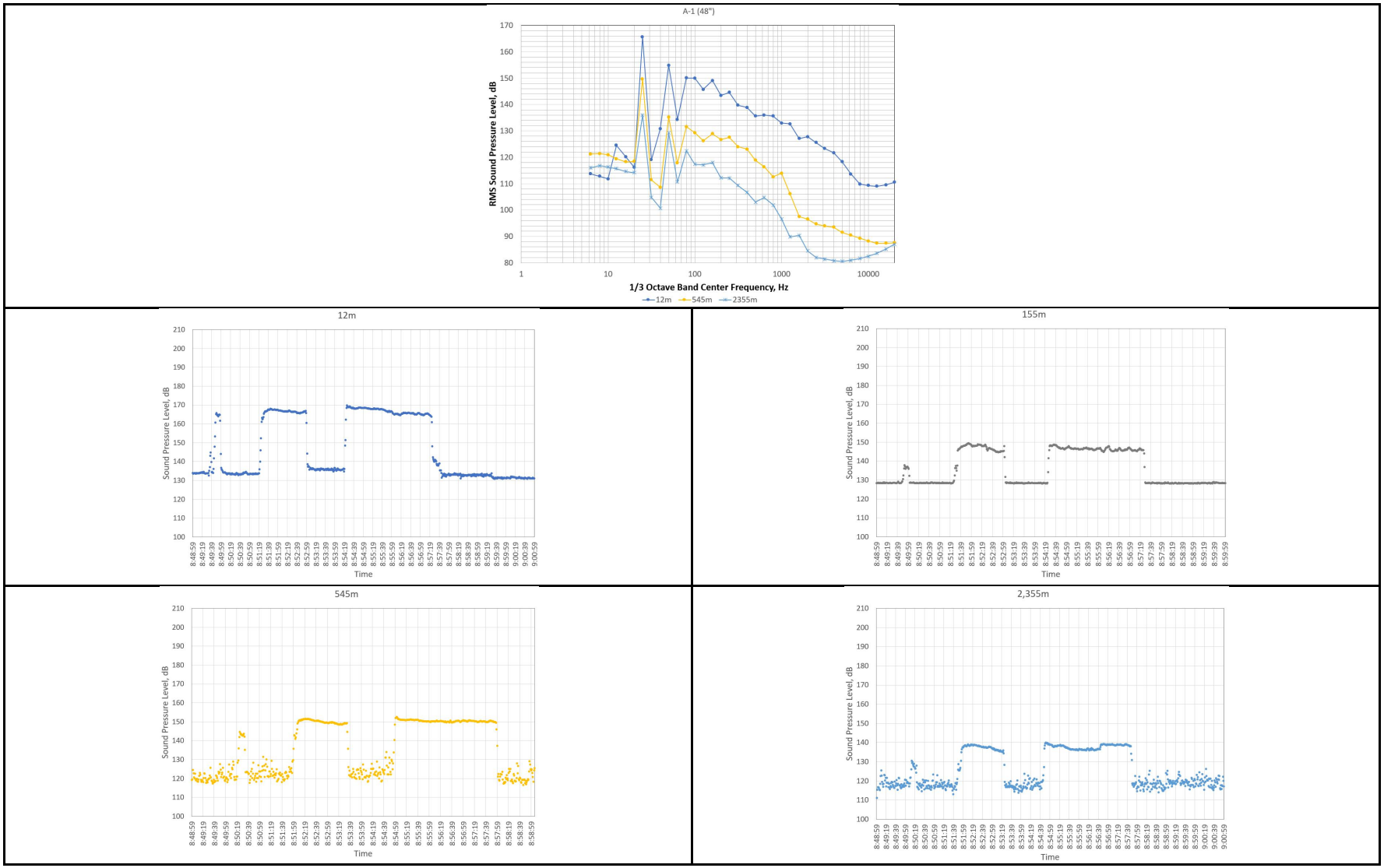


Figure 5-2. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 10, 2020 (Pile A-1)

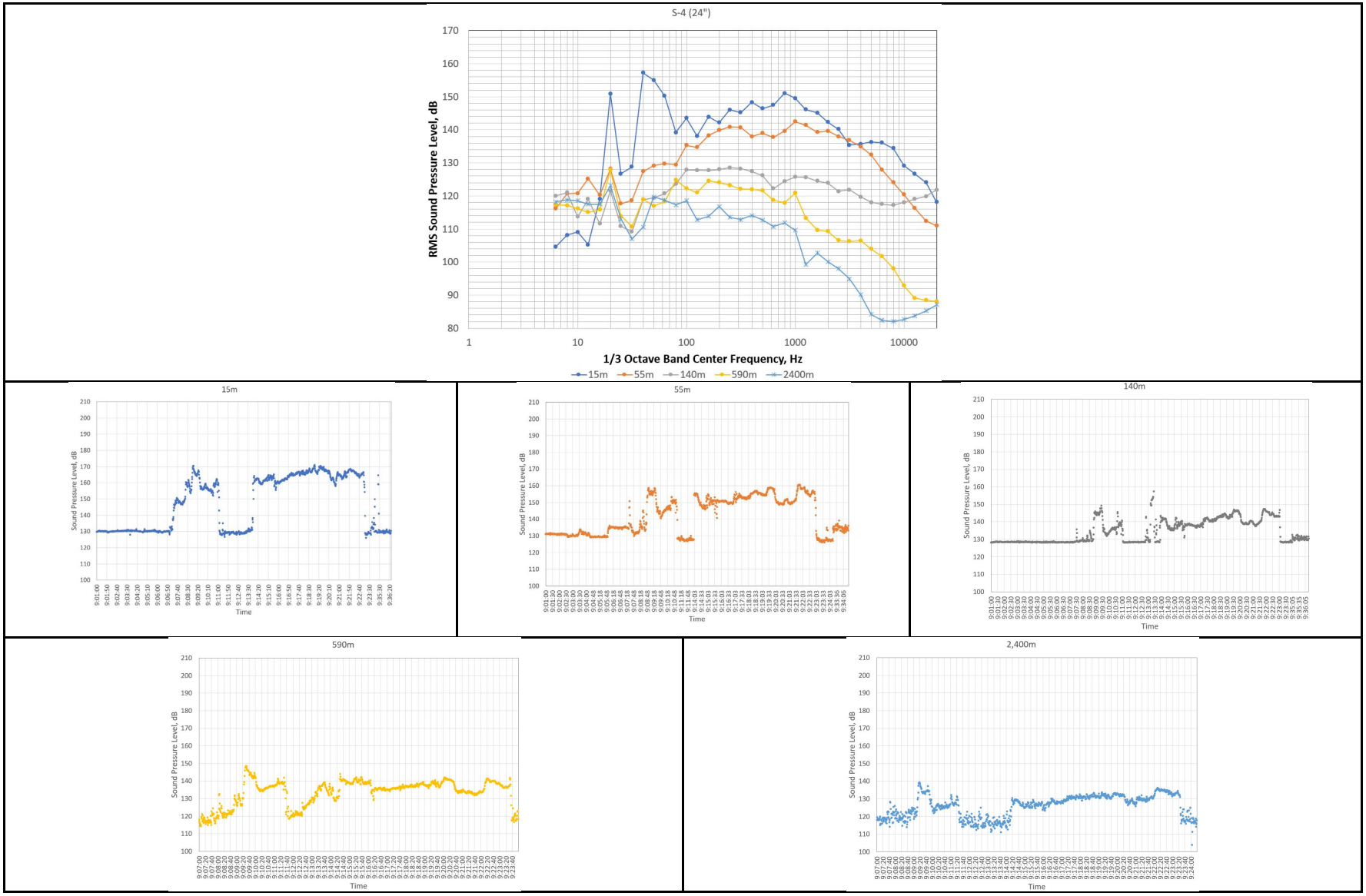


Figure 5-3. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 10, 2020 (Pile S-4)

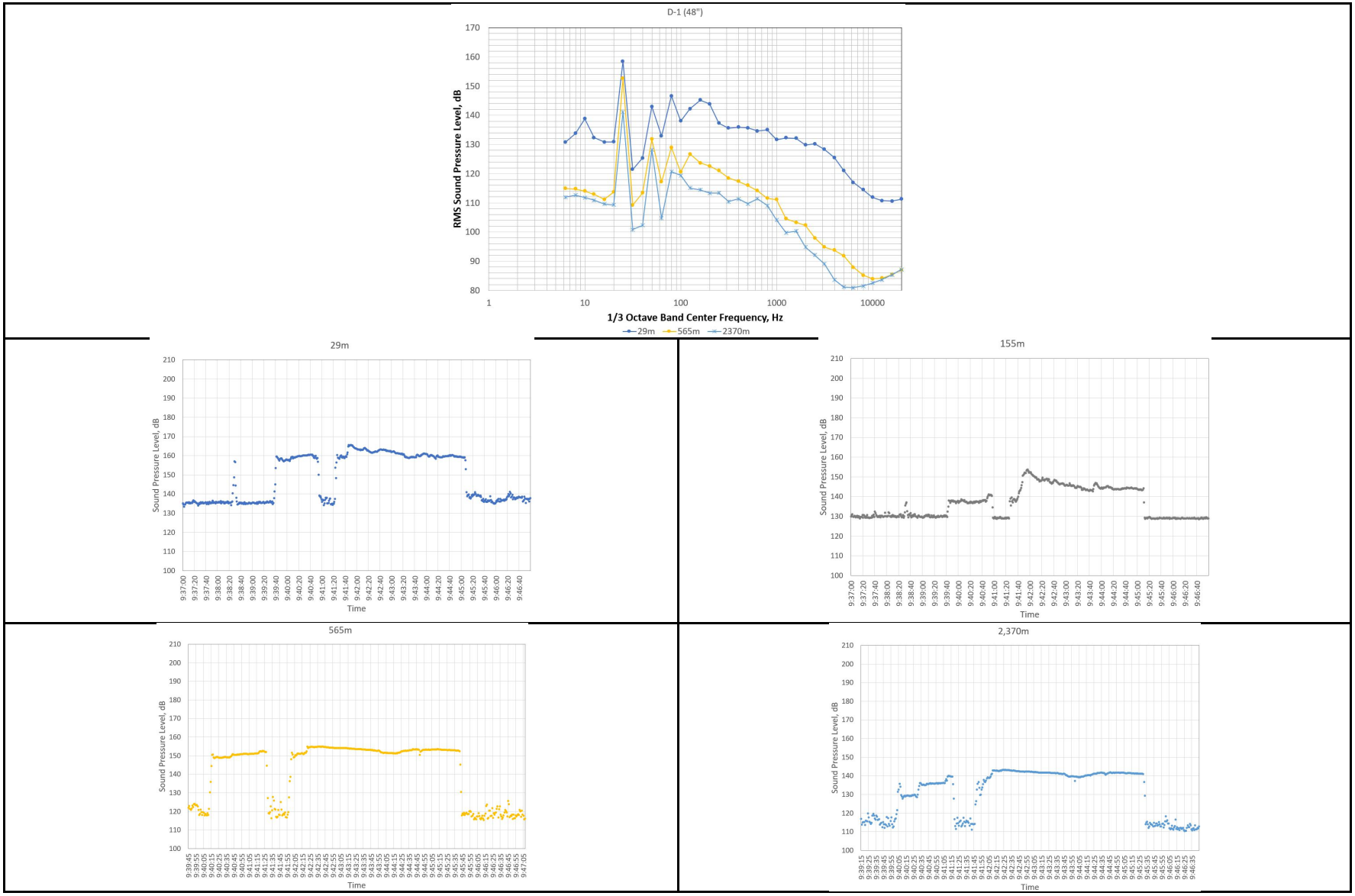


Figure 5-4. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 10, 2020 (Pile D-1)

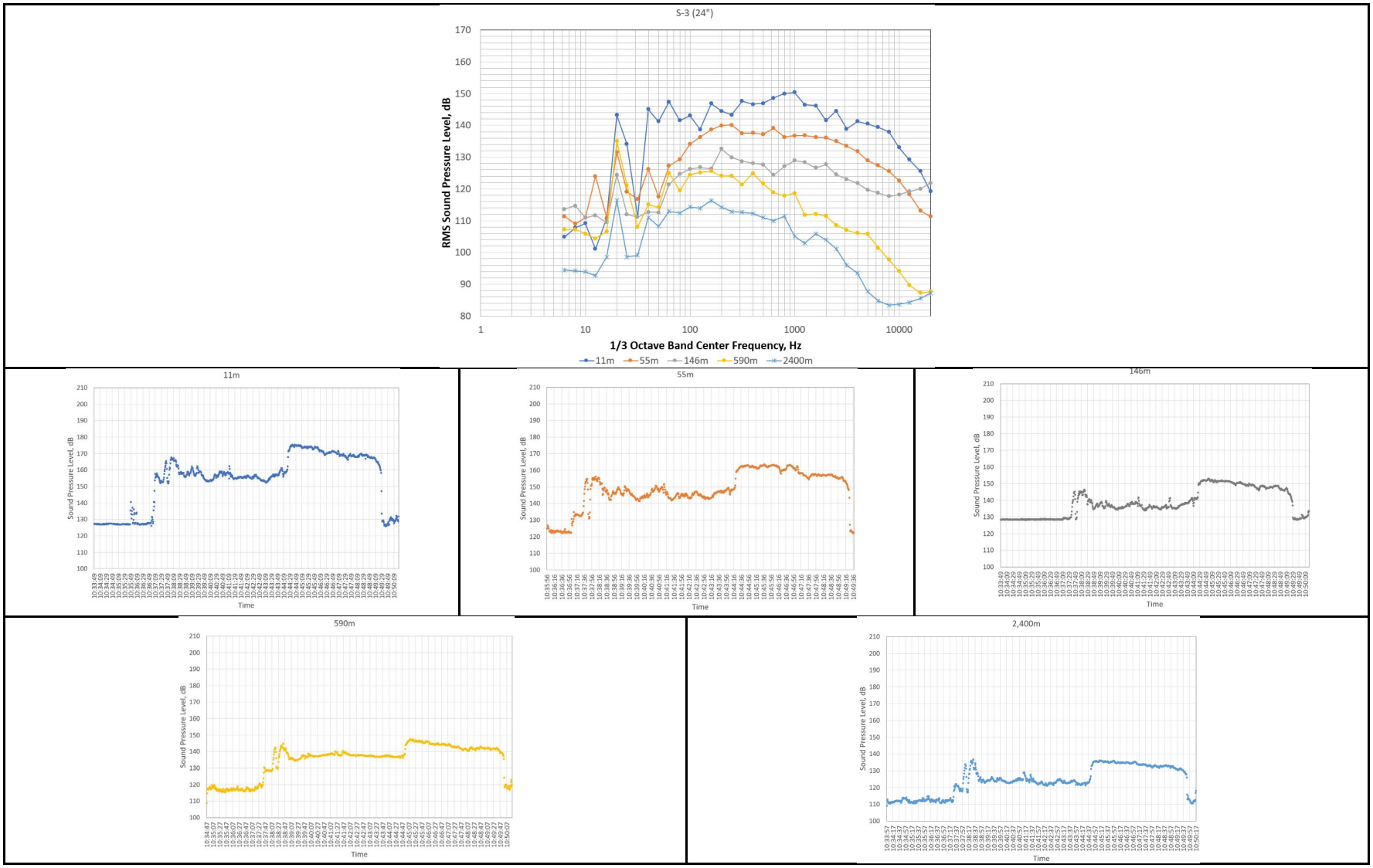


Figure 5-5. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 10, 2020 (Pile S-3)

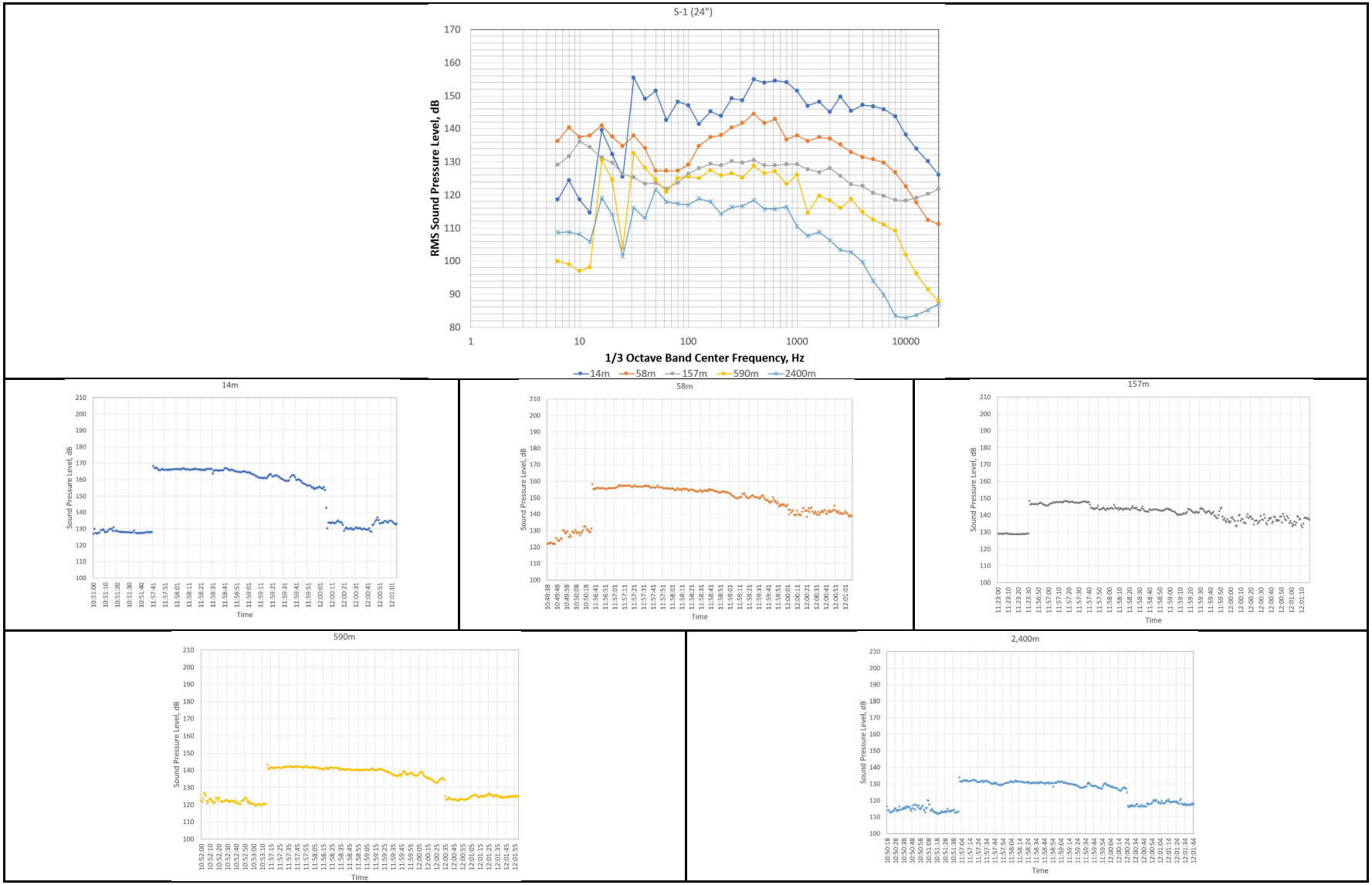


Figure 5-6. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 10, 2020 (Pile S-1)

Table 5-3. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 10, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
8:51 to 8:57	A-1 (48-inch)	12	130	167	167	12.2	168.7	N/A			N/A	N/A
		545	125	150	150			N/A				
		2,355	120	138	138			N/A				
9:06 to 9:23	S-4 (24-inch)	15	130	164	163	15.3	165.2	N/A			N/A	N/A
		55	135	152	152			N/A				
		590	122	137	137			N/A				
		2,400	118	130	130			N/A				
9:39 to 9:45	D-1 (48-inch)	29	135	160	160	8.8	165.2	N/A			N/A	N/A
		565	122	153	153			N/A				
		2,370	115	142	142			N/A				
10:37 to 10:49	S-3 (24-inch)	11	125	159	159	13.6	160.3	N/A			N/A	N/A
		55	125	150	150			N/A				
		590	120	139	139			N/A				
		2,400	115	126	126			N/A				
11:46 to 12:00	S-1 (24-inch)	14	132	165	165	14.7	166.1	N/A			N/A	N/A
		58	135	153	153			N/A				
		590	125	141	141			N/A				
		2,400	118	131	131			N/A				

Table 5-4. Summary of RMS data in the north direction for piles driven on June 10, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
8:51 to 8:57	A-1 (48-inch)	12	130	167	167
		155	130	147	147
9:06 to 9:23	S-4 (24-inch)	15	130	164	164
		55	135	152	152
		140	130	140	140
9:39 to 9:45	D-1 (48-inch)	29	135	160	160
		155	135	145	145
10:37 to 10:49	S-3 (24-inch)	11	125	159	159
		55	125	150	150
		146	130	141	141
11:46 to 12:00	S-1 (24-inch)	14	132	165	165
		58	135	153	153
		157	135	143	143

5.1.3 June 12, 2020, Measurement Results

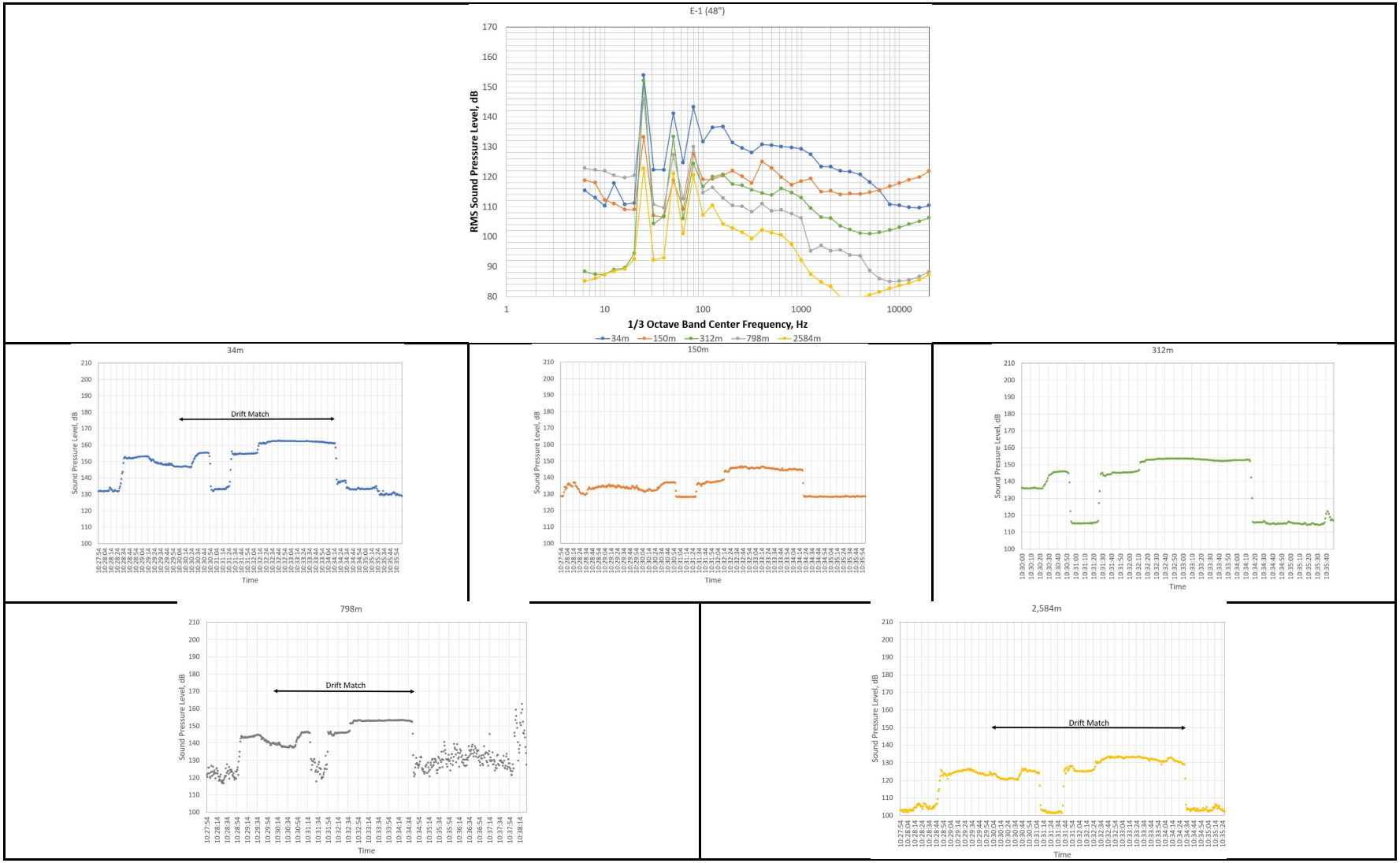


Figure 5-7. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 12, 2020 (Pile E-1)

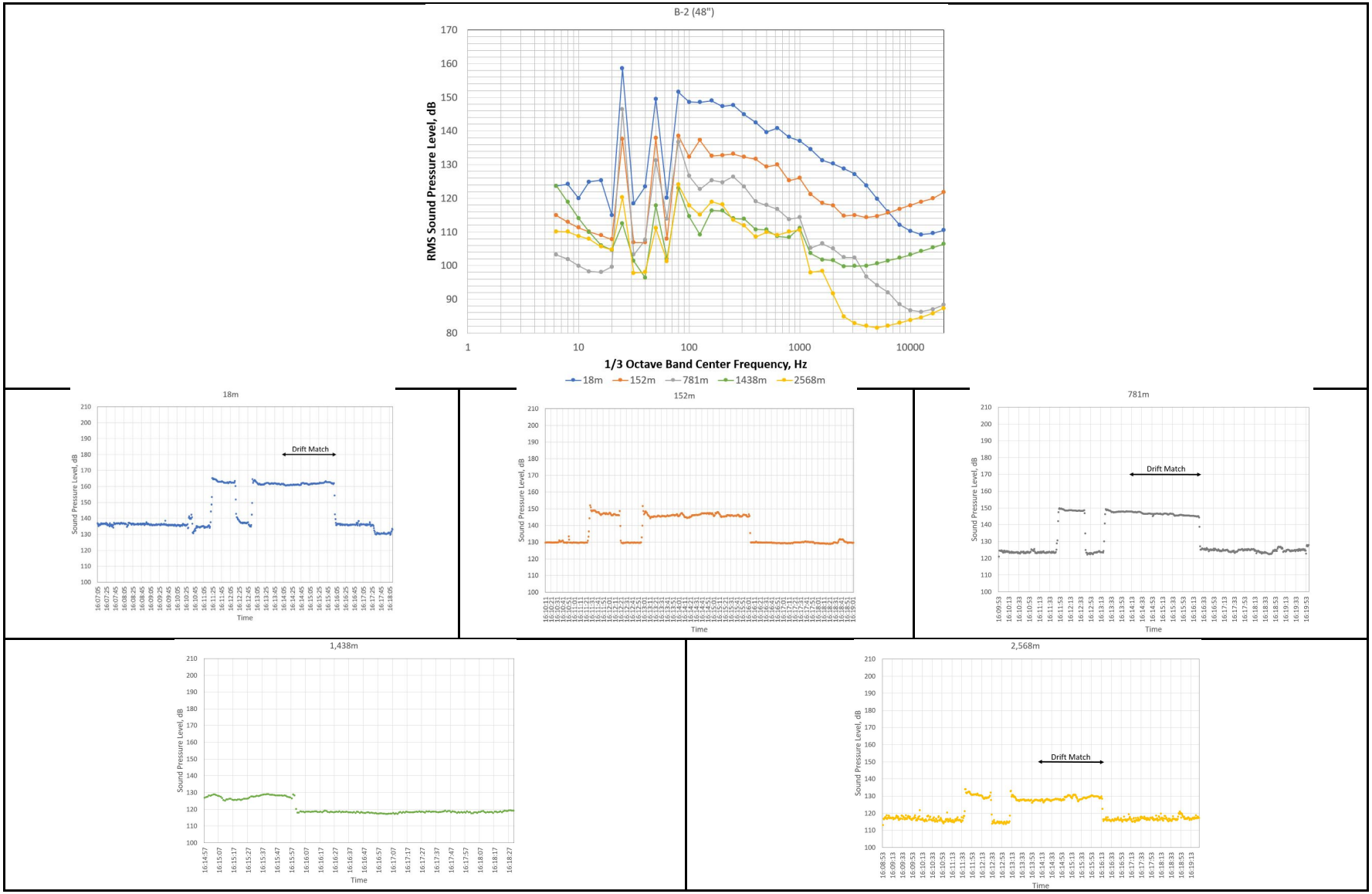


Figure 5-8. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 12, 2020 (Pile B-2)

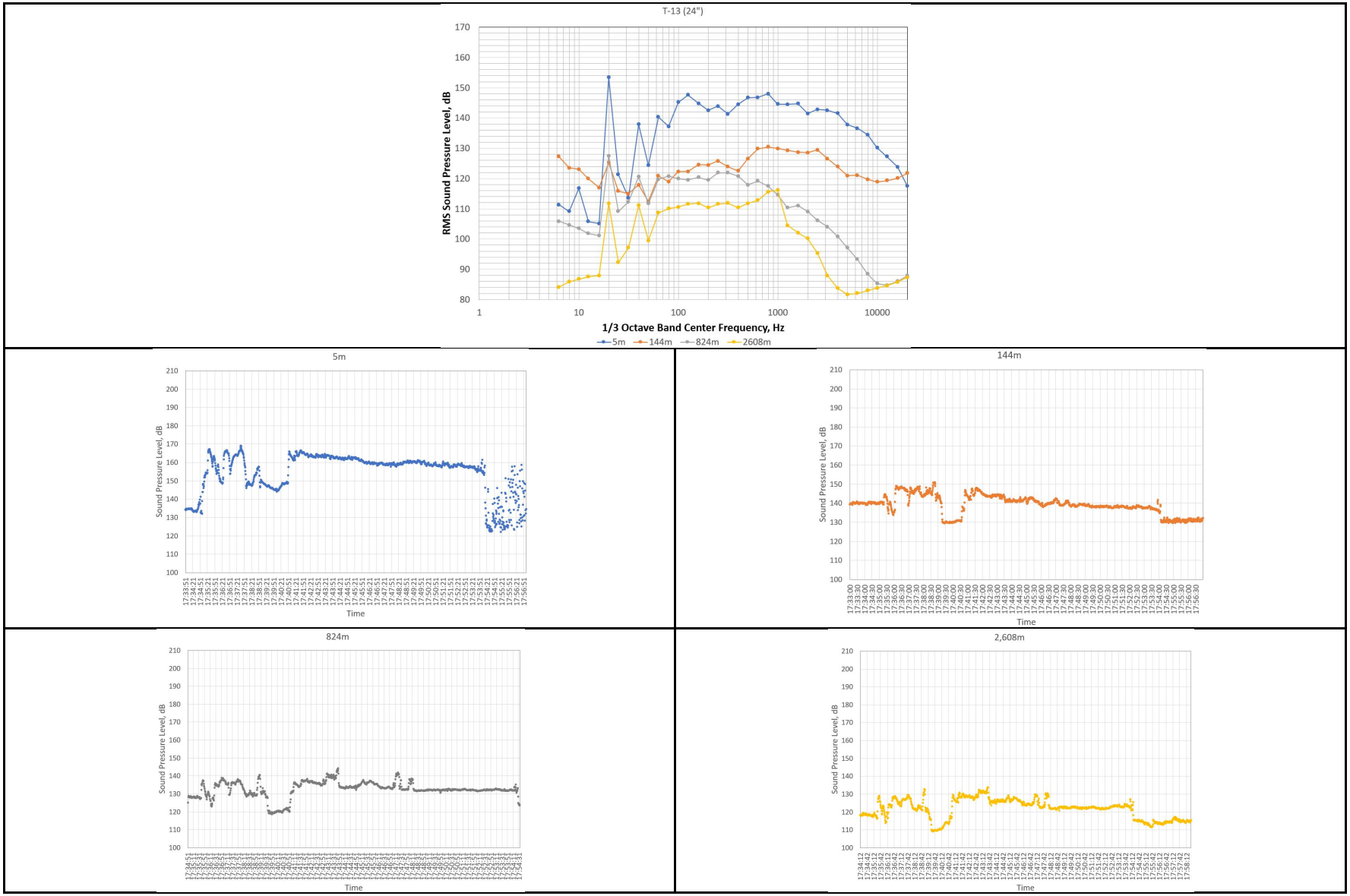


Figure 5-9. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 12, 2020 (Pile T-13)

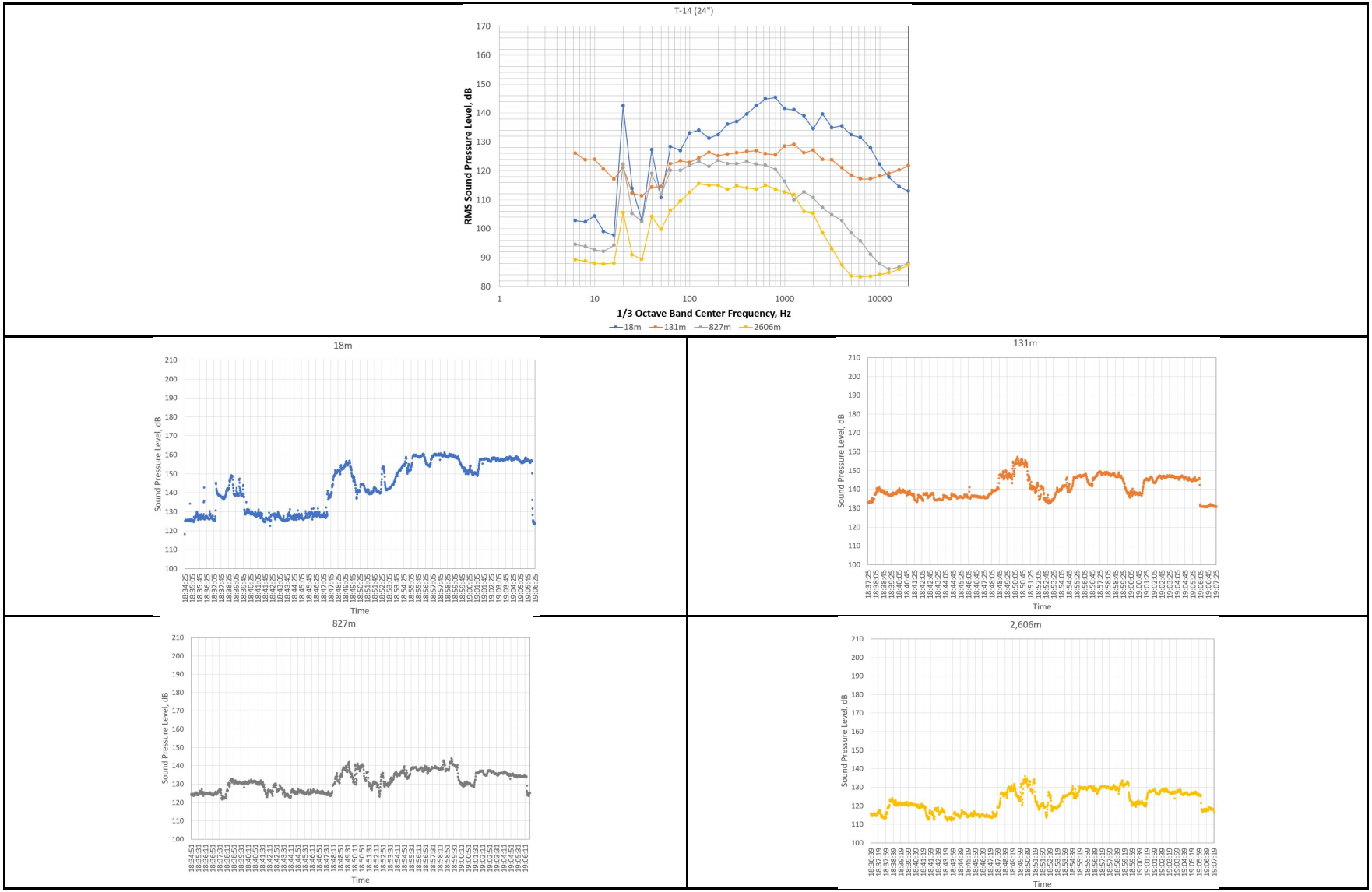


Figure 5-10. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 12, 2020 (Pile T-14)

Table 5-5. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 12, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
10:28 to 10:34	E-1 (48-inch)	34	135	155	155	13.6	164.3	135	161	161	15.4	171.9
		312	N/A					118	152	152		
		798	128	146	146			128	147	147		
		2,584	105	126	126			105	130	130		
16:11 to 16:16	B-2 (48-inch)	18	135	162	162	13.8	167.0	135	162	162	15.2	167.0
		781	125	147	147			125	146	146		
		1,438	N/A					120	128	127		
		2,568	118	129	129			118	130	130		
17:35 to 17:56	T-13 (24-inch)	5	135	160	160	12.9	156.4	N/A			N/A	N/A
		824	120	133	133			N/A				
		2,608	115	124	123			N/A				
18:37 to 19:06	T-14 (24-inch)	18	130	154	154	12.2	157.4	N/A			N/A	N/A
		827	125	135	135			N/A				
		2,606	118	127	126			N/A				

Table 5-6. Summary of RMS data in the north direction for piles driven on June 12, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
10:28 to 10:34	E-1 (48-inch)	34	135	155	156
		150	130	137	139
16:11 to 16:16	B-2 (48-inch)	18	135	162	162
		152	130	146	146
17:35 to 17:56	T-13 (24-inch)	5	135	160	160
		144	130	141	141
18:37 to 19:06	T-14 (24-inch)	18	130	154	154
		131	130	140	140

5.1.4 June 14, 2020, Measurement Results

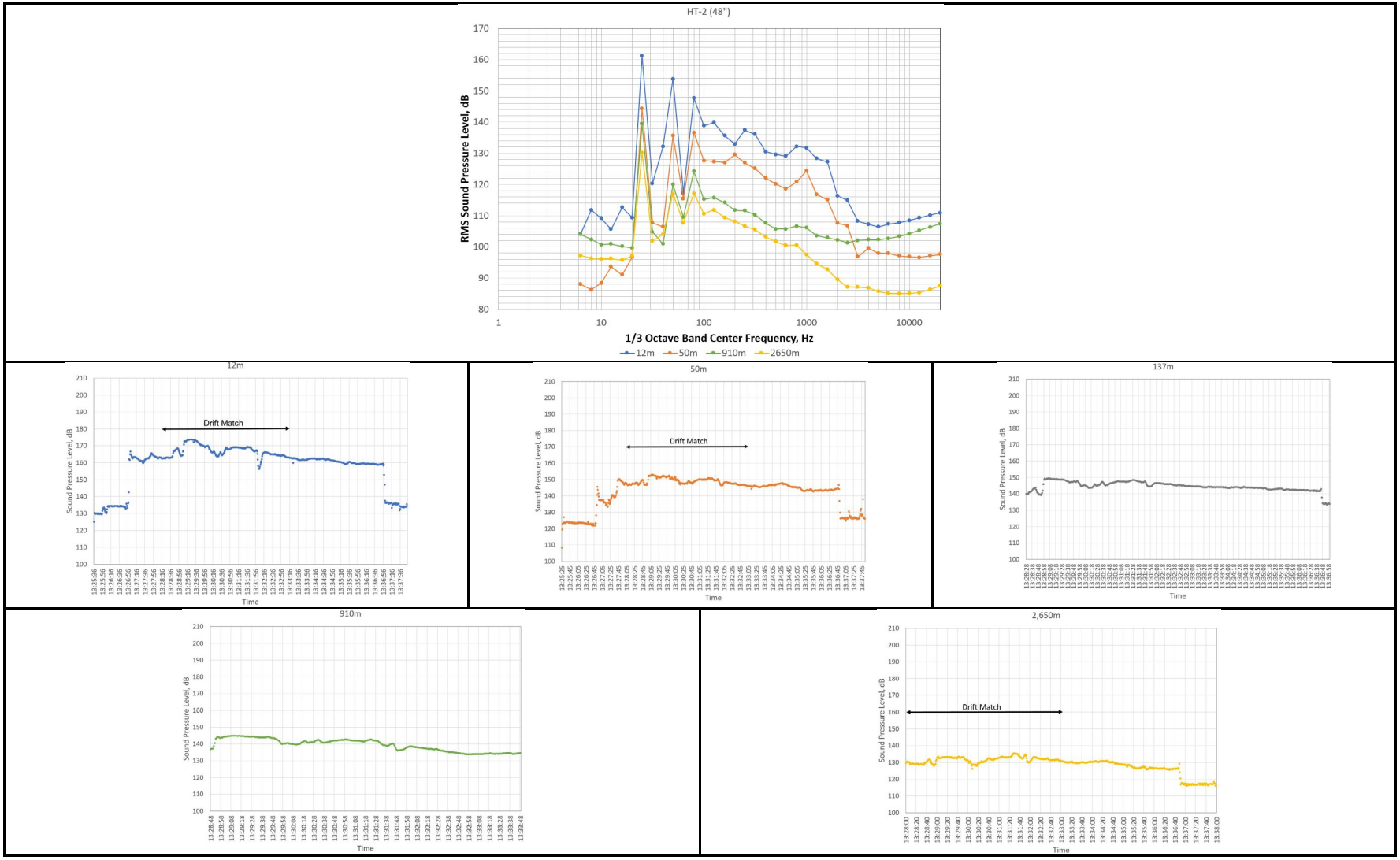


Figure 5-11. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 14, 2020 (Pile HT-2)

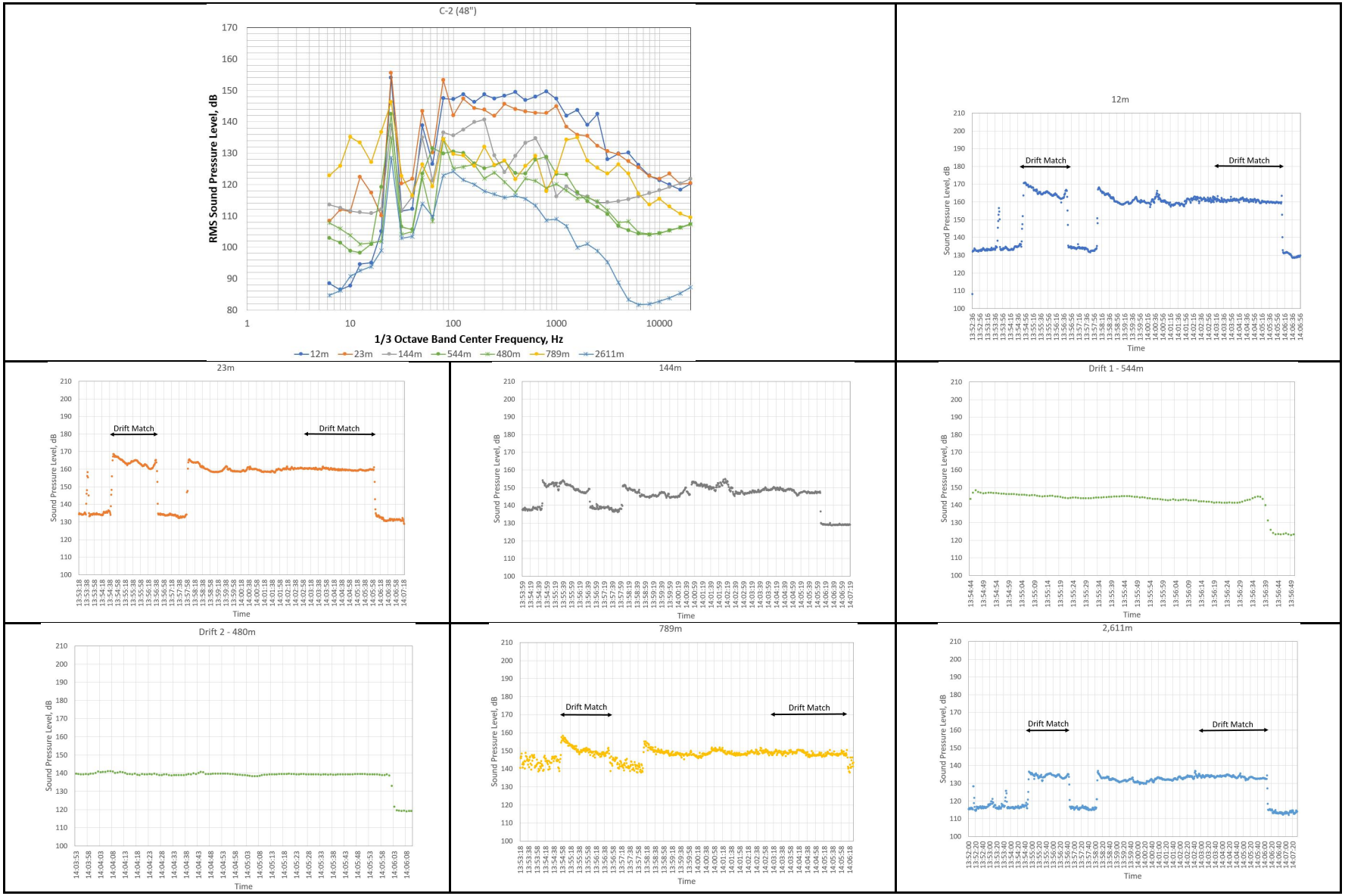


Figure 5-12. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 14, 2020 (Pile C-2)

Table 5-7. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters from June 14, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)														
			Full Event					Drift Match Segment 1 Only					Drift Match Segment 2 Only				
			Background	Measured	Project	TL Coeff.	Level at 10 meters	Background	Measured	Project	TL Coeff.	Level at 10 meters	Background	Measured	Project	TL Coeff.	Level at 10 meters
13:27 to 13:36	HT-2 (48-inch)	12	135	163	163	12.7	160.6	135	167	167	13.1	163.7	N/A			N/A	N/A
		50	135	147	147			135	148	148			N/A				
		910	N/A					120	140	140			N/A				
		2,650	118	131	131			118	132	132			N/A				
13:54 to 14:06	C-2 (48-inch)	12	132	161	161	10.7	163.5	132	165	165	12.2	167.4	132	160	160	10.8	162.3
		23	135	160	160			135	164	164			135	160	160		
		544	N/A					120	144	144			N/A				
		480	N/A					N/A					120	140	140		
		789	144	149	147			144	150	149			144	148	148		
		2,611	115	133	133			115	135	135			115	134	134		

Table 5-8. Summary of RMS data in the north direction from June 14, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
13:27 to 13:36	HT-2 (48-inch)	12	135	163	164
		50	135	147	147
		137	130	145	145
13:54 to 14:06	C-2 (48-inch)	12	132	161	162
		23	135	160	161
		144	130	149	149

5.1.5 June 16, 2020, Measurement Results

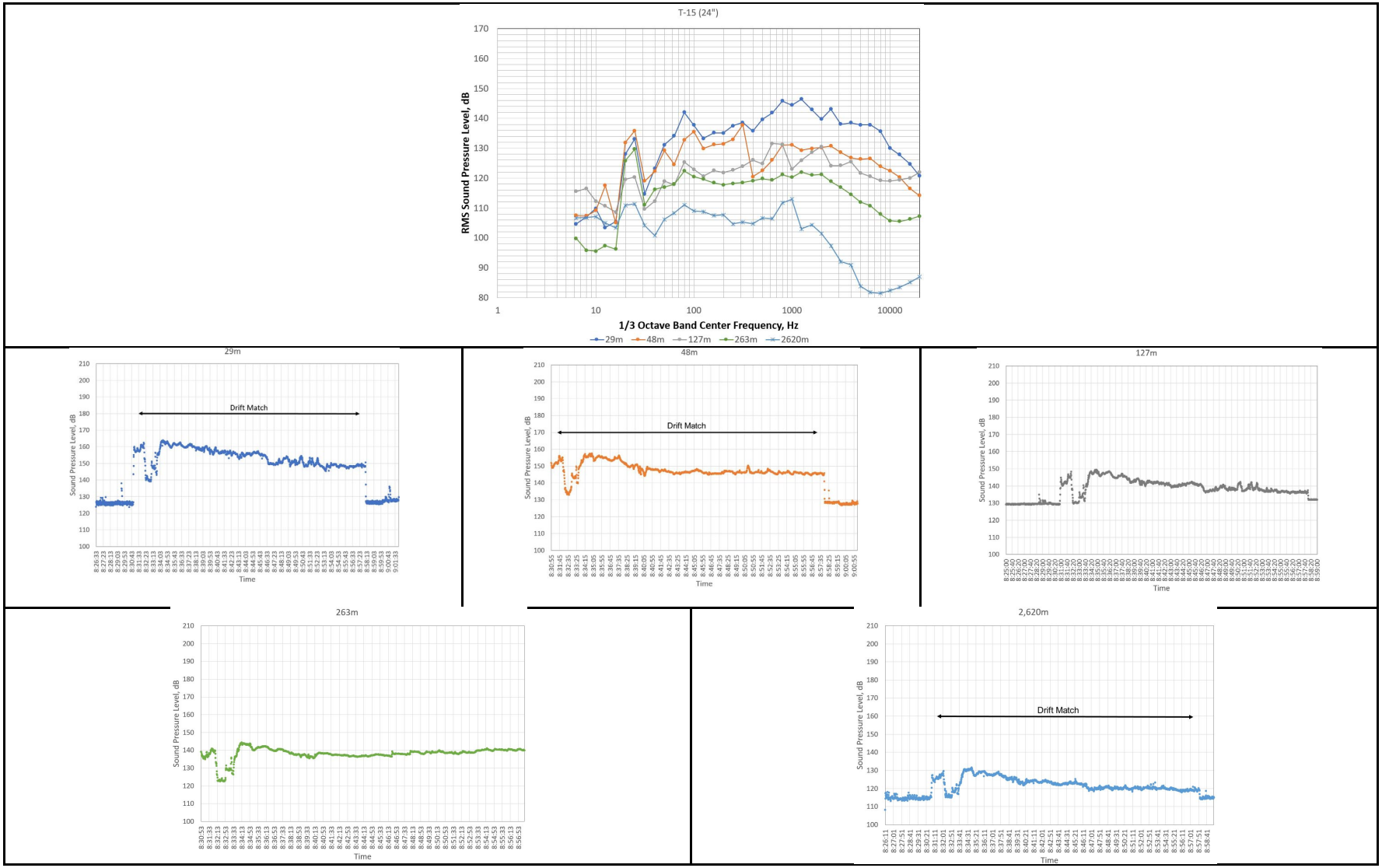


Figure 5-13. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 16, 2020 (Pile T-15)

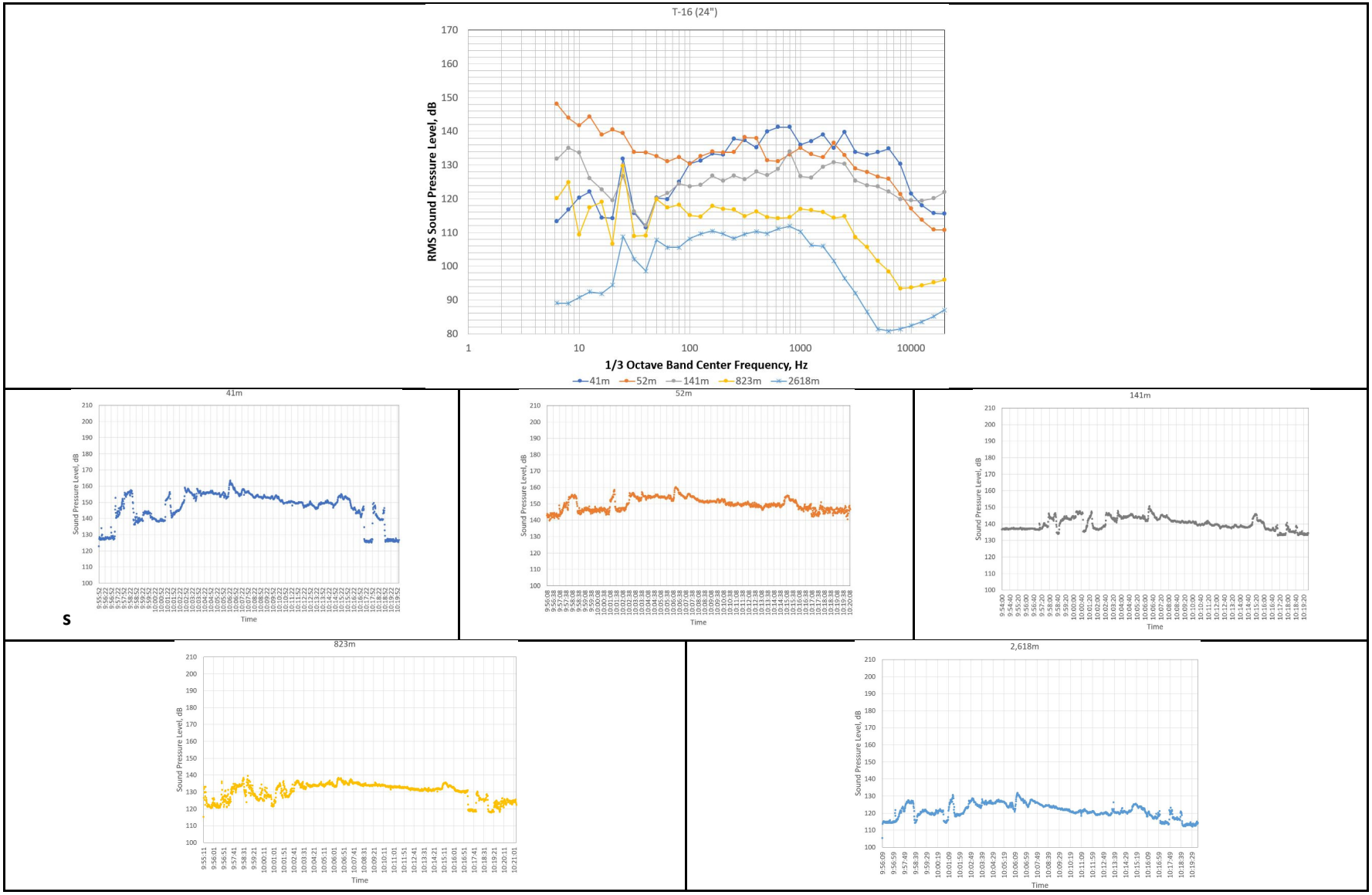


Figure 5-14. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 16, 2020 (Pile T-16)

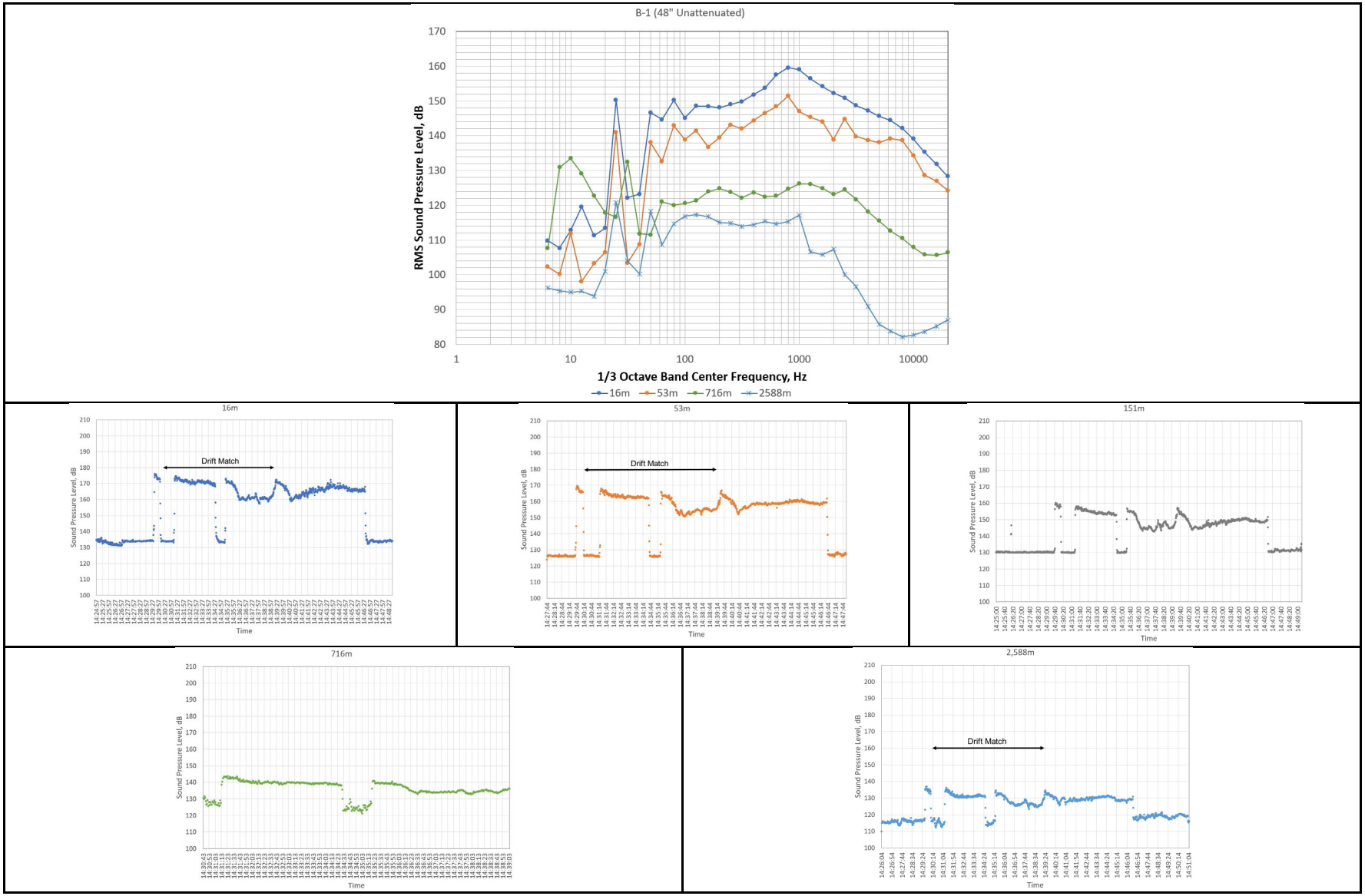


Figure 5-15. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 16, 2020 (Pile B-1)

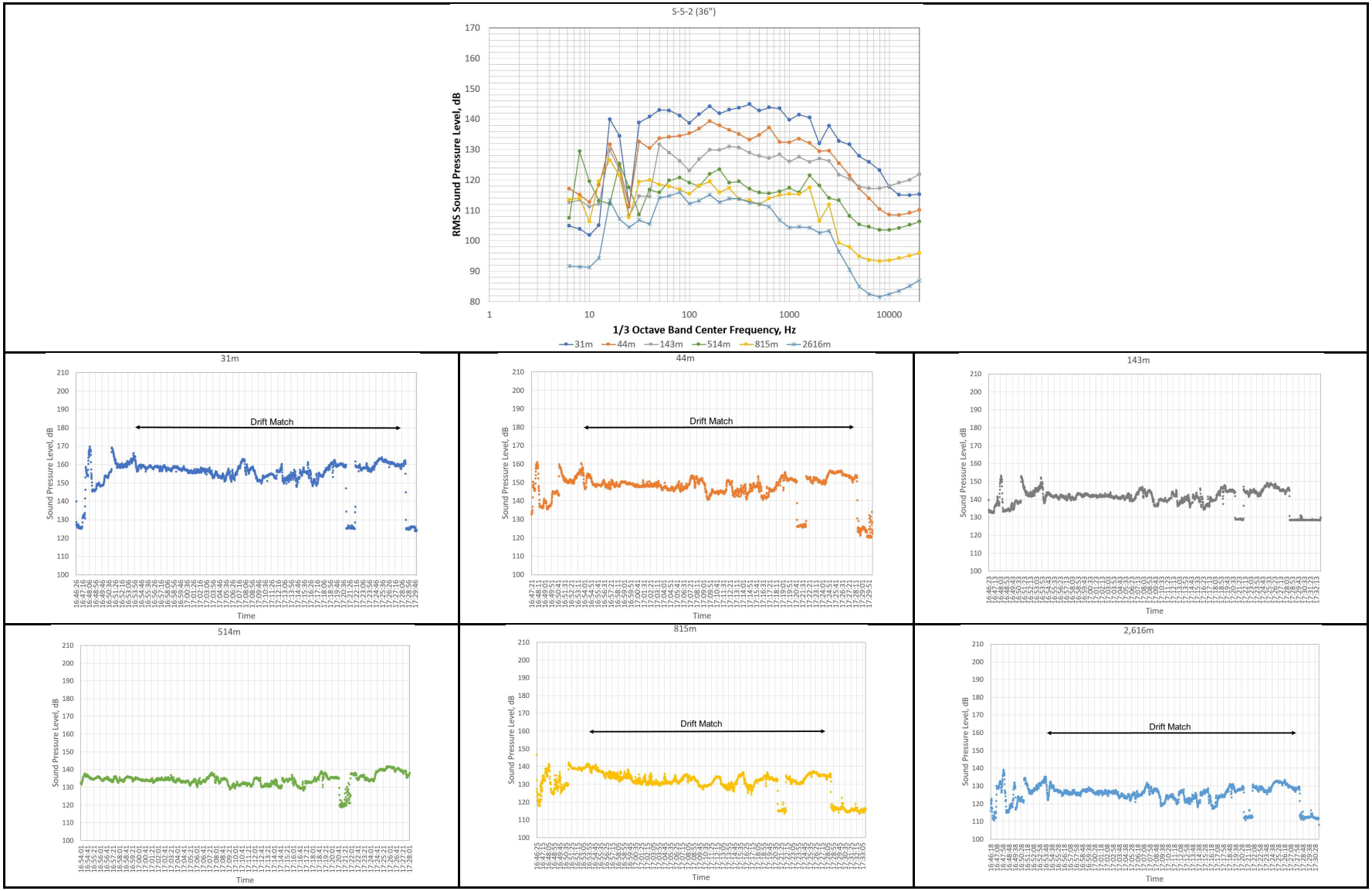


Figure 5-16. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 16, 2020 (Pile S-5)

Table 5-9. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 16, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
8:31 to 8:58	T-15 (24-inch)	29	128	155	155	16.8	159.4	128	155	155	16.6	159.7
		48	129	147	147			129	147	147		
		263	N/A					122	139	139		
		2,620	117	122	120			117	122	120		
9:58 to 10:18	T-16 (24-inch)	41	128	150	150	15.6	160.1	N/A			N/A	N/A
		52	128	150	150			N/A				
		823	120	133	133			N/A				
		2,618	114	122	121			N/A				
14:28 to 14:46	B-1 (48-inch, unattenuated)	16	135	167	167	16.8	170.8	135	170	170	18.2	174.2
		53	128	159	159			128	162	162		
		716	N/A					125	139	139		
		2,588	118	130	130			118	131	131		
16:47 to 17:28	S-5 (36-inch, Bent 2)	31	125	157	157	14.4	161.2	125	157	157	14.7	161.1
		44	127	149	149			127	149	149		
		514	N/A					120	134	134		
		815	117	133	133			117	133	133		
		2,616	114	127	127			114	127	127		

Table 5-10. Summary of RMS data in the north direction for piles driven on June 16, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
8:31 to 8:58	T-15 (24-inch)	29	128	155	154
		48	129	147	148
		127	130	141	141
9:58 to 10:18	T-16 (24-inch)	41	128	150	150
		52	128	150	150
		141	130	142	142
14:28 to 14:46	B-1 (48-inch, unattenuated)	16	135	167	167
		53	128	159	160
		151	130	149	150
16:47 to 17:28	S-5 (36-inch, Bent 2)	31	125	157	157
		44	127	149	149
		143	130	142	143

5.1.6 June 17, 2020, Measurement Results

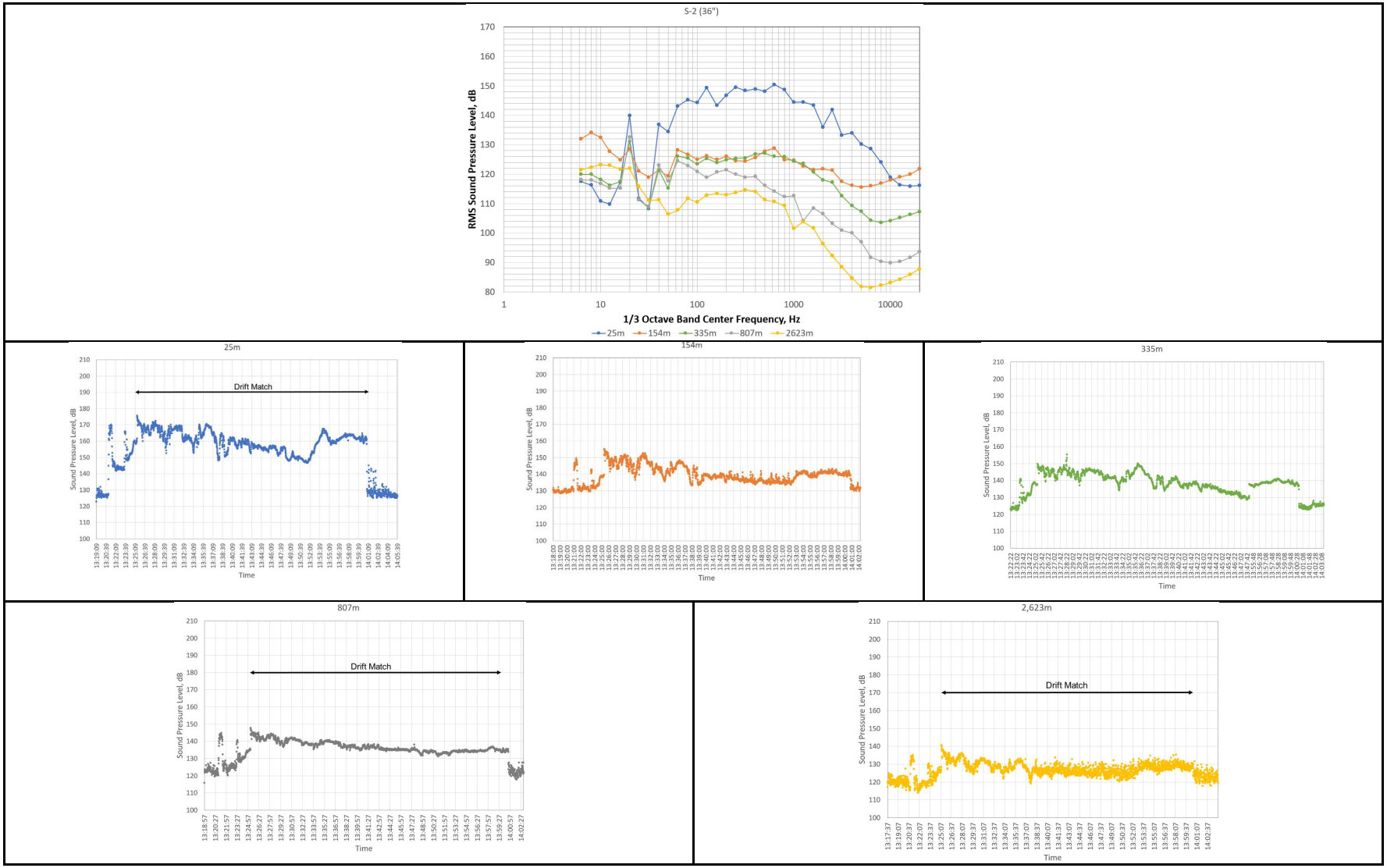


Figure 5-17. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 17, 2020 (Pile S-2)

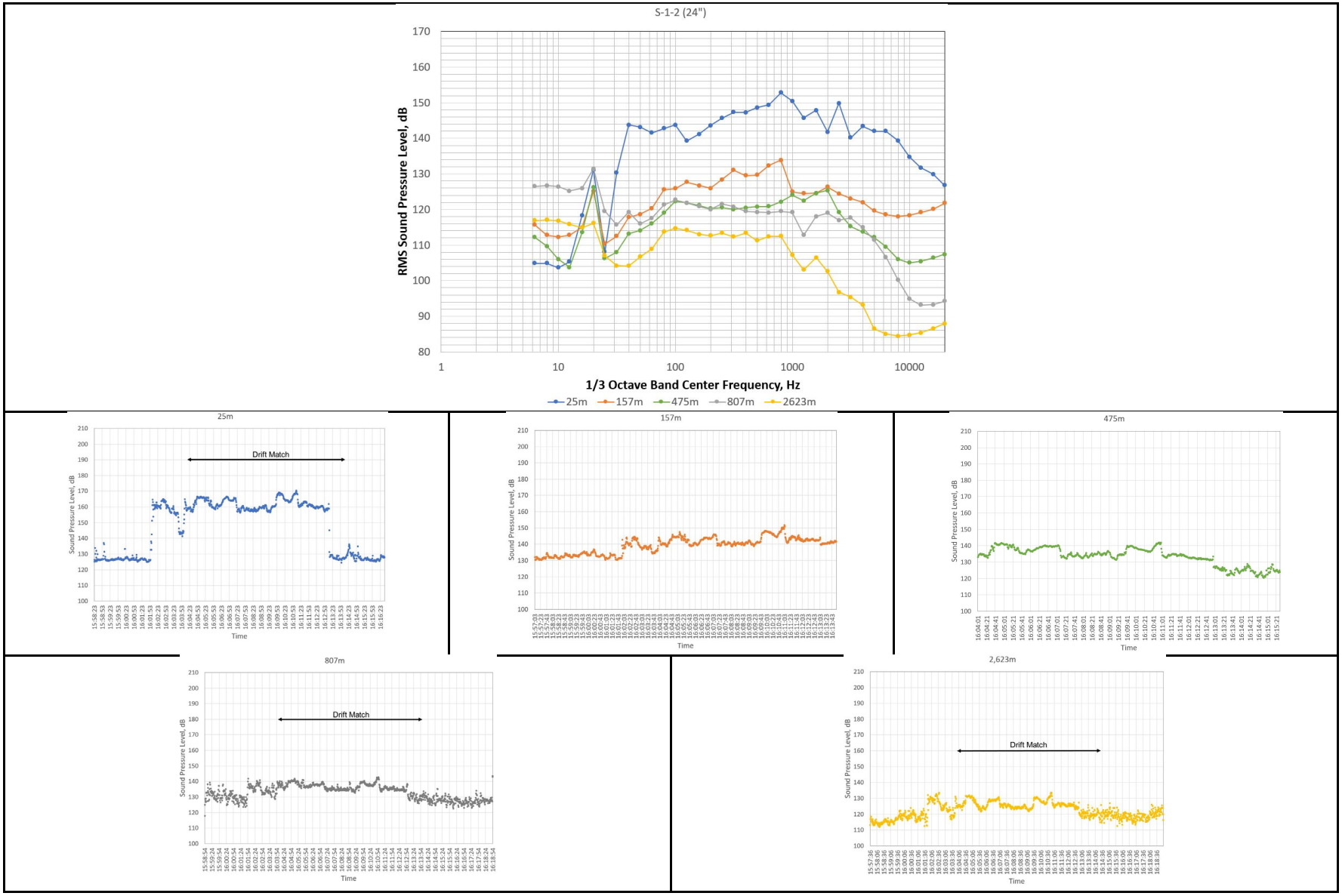


Figure 5-18. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 17, 2020 (Pile S-1)

Table 5-11. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 17, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
13:21 to 14:01	S-2 (36-inch, Bent 2)	25	130	161	161	17.3	166.0	130	161	161	17.2	167.6
		335	N/A					125	140	140		
		807	125	136	136			125	136	136		
		2,623	124	128	126			124	128	126		
16:01 to 16:14	S-1 (24-inch)	25	128	161	161	17.8	168.2	128	161	161	17.7	167.6
		475	N/A					142	135	135		
		807	130	136	135			143	137	136		
		2,623	120	126	125			134	126	125		

Table 5-12. Summary of RMS data in the north direction for piles driven on June 17, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
13:21 to 14:01	S-2 (36-inch, Bent 2)	25	130	161	160
		154	130	140	140
16:01 to 16:14	S-1 (24-inch)	25	128	161	161
		157	130	142	142

5.1.7 June 19, 2020, Measurement Results

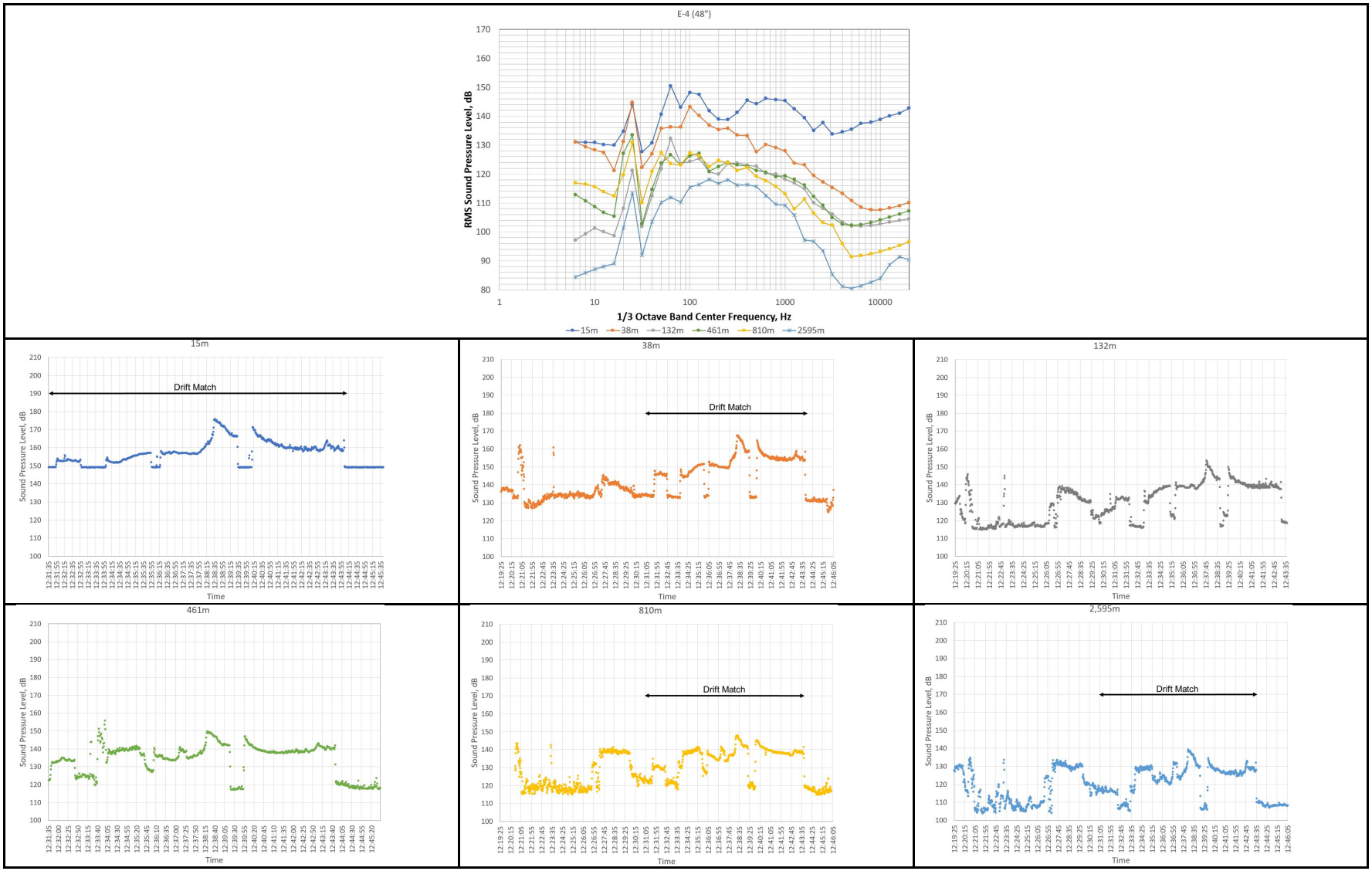


Figure 5-19. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 19, 2020 (Pile E-4)

Table 5-13. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 19, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
12:27 to 12:44	E-4 (48-inch)	15	150	159	158	12.3	160.1	150	159	159	13.3	161.7
		38	130	151	151			130	154	154		
		461	N/A					120	139	139		
		810	120	139	139			120	139	139		
		2,595	110	129	129			110	128	128		

Table 5-14. Summary of RMS data in the north direction for piles driven on June 19, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
12:27 to 12:44	E-4 (48-inch)	15	150	159	158
		38	130	151	151
		132	130	139	138

5.1.8 June 20, 2020, Measurement Results

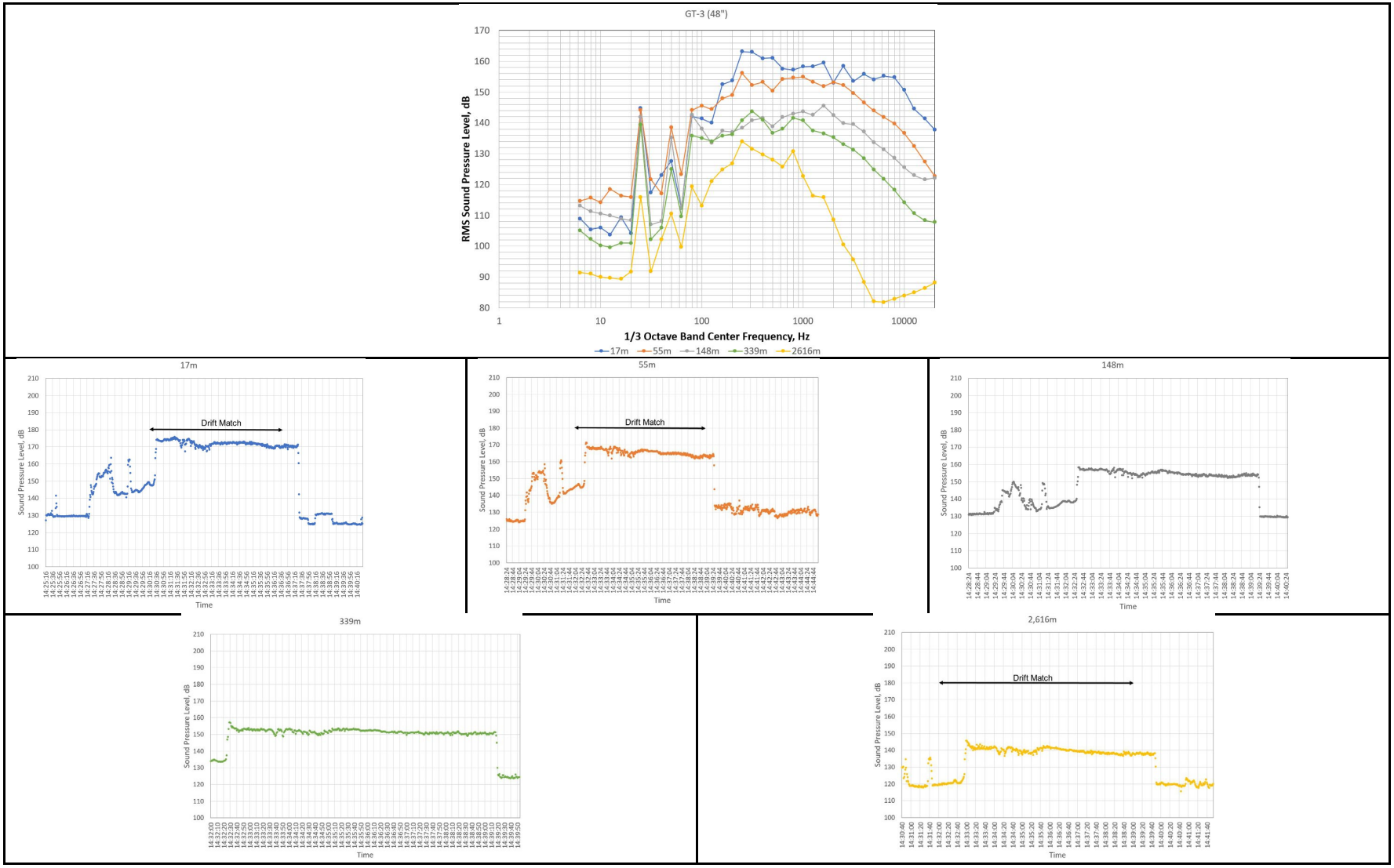


Figure 5-20. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 20, 2020 (Pile GT-3)

Table 5-15. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 20, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
14:28 to 14:40	GT-3 (48-inch)	17	130	172	172	15.2	175.9	130	172	172	15.2	175.8
		55	132	165	165			132	165	165		
		339	N/A					130	152	152		
		2,616	122	139	139			122	139	139		

Table 5-16. Summary of RMS data in the north direction for piles driven on June 20, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
14:28 to 14:40	GT-3 (48-inch)	17	130	172	170
		55	132	165	164
		148	130	154	154

5.1.9 June 23, 2020, Measurement Results

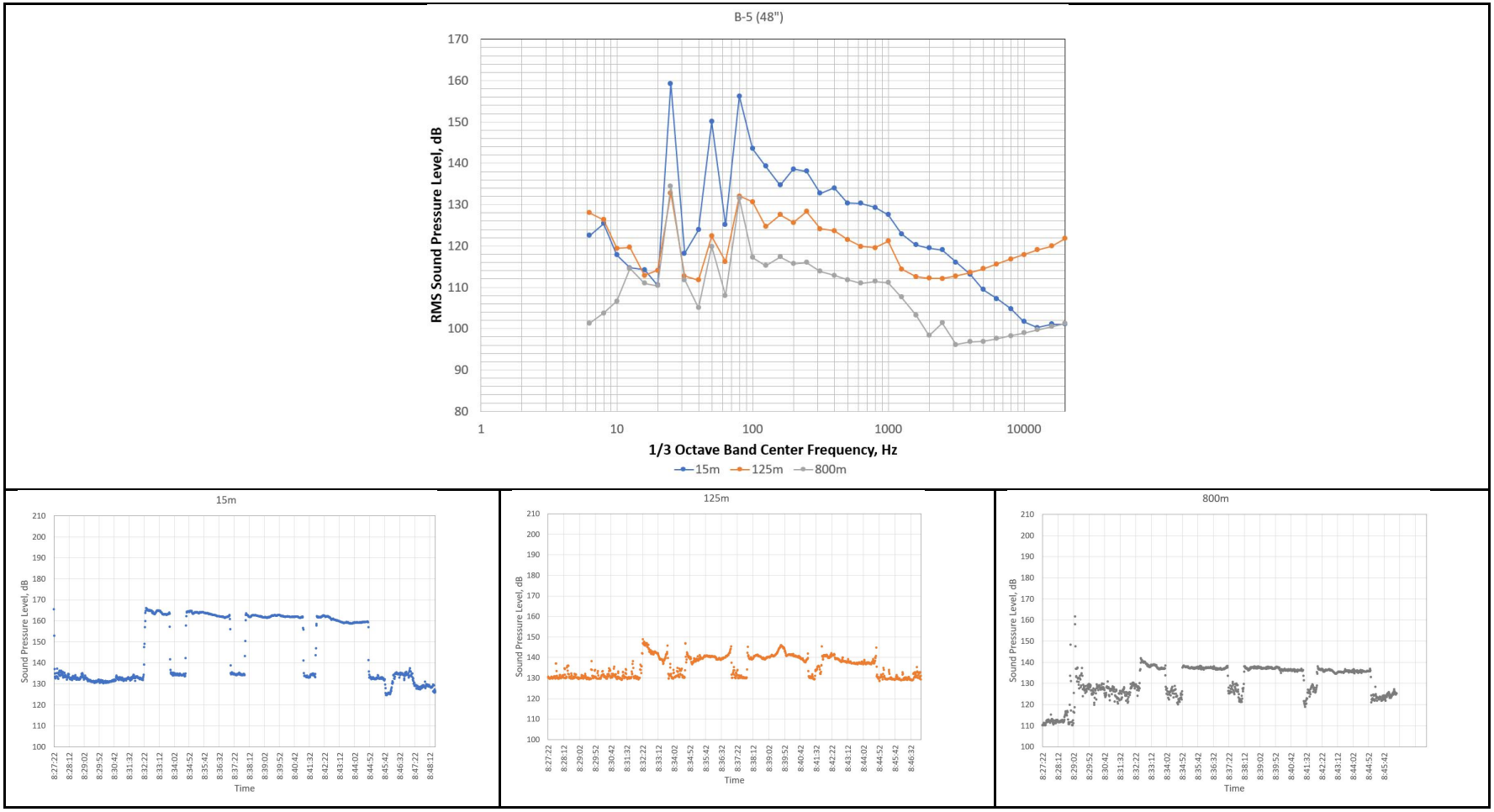


Figure 5-21. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 23, 2020 (Pile B-5)

Table 5-17. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 23, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
8:32 to 8:44	B-5 (48-inch)	15	135	162	162	14.5	164.6	N/A			N/A	N/A
		800	127	137	137			N/A				

Table 5-18. Summary of RMS data in the north direction for piles driven on June 23, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
8:32 to 8:44	B-5 (48-inch)	15	135	162	162
		125	135	140	140

5.1.10 June 24, 2020, Measurement Results

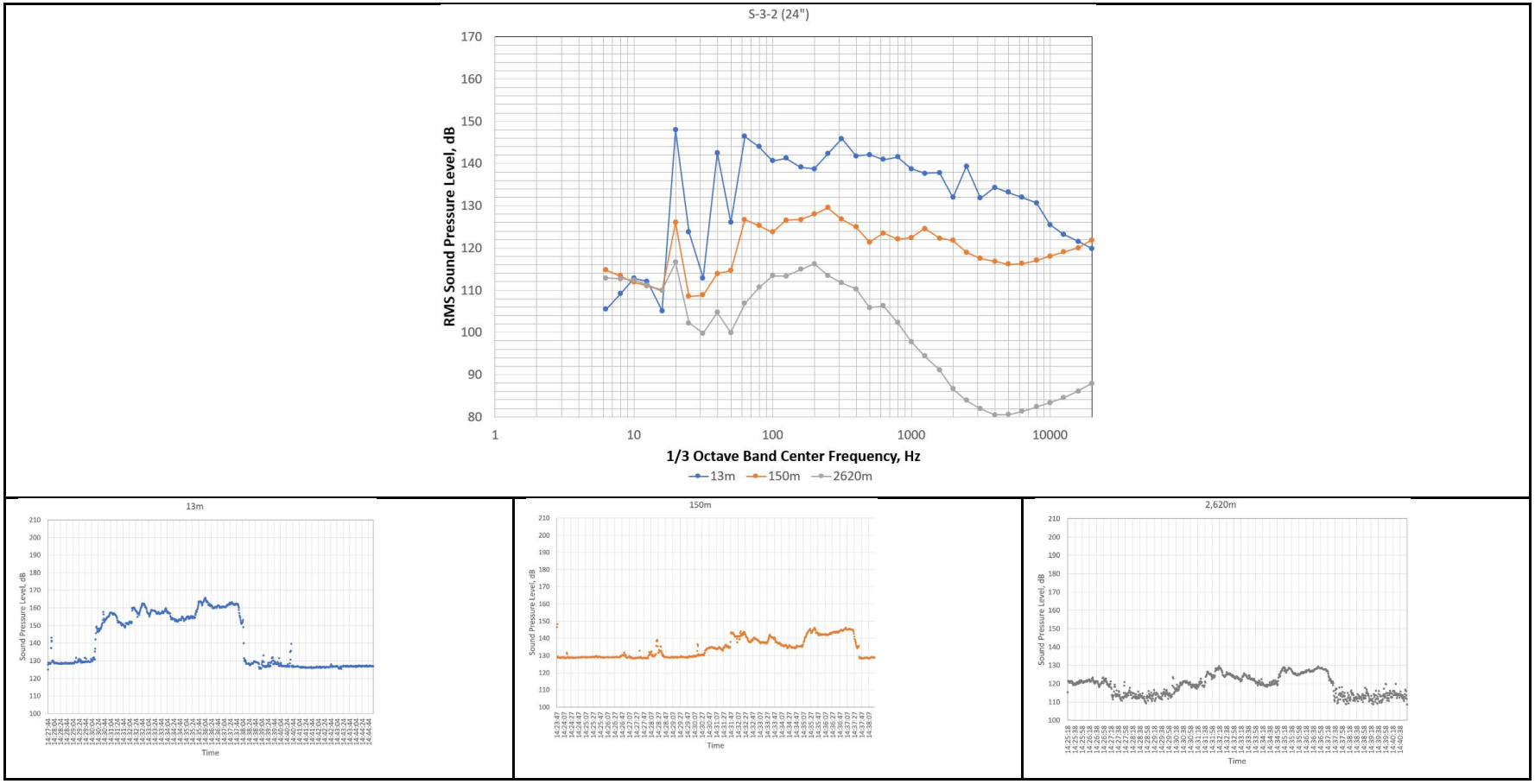


Figure 5-22. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 24, 2020 (Pile S-3)

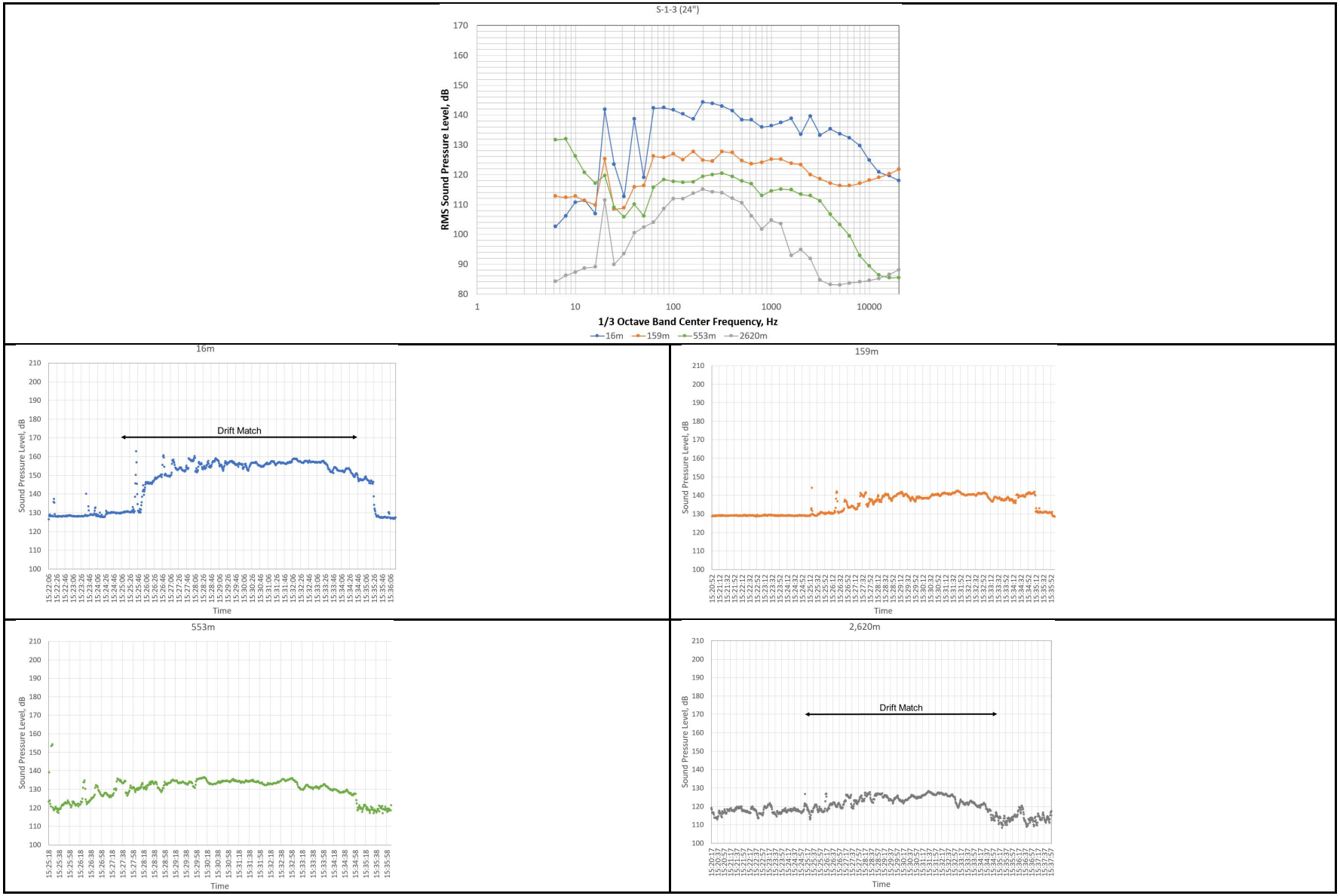


Figure 5-23. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 24, 2020 (Pile S-1)

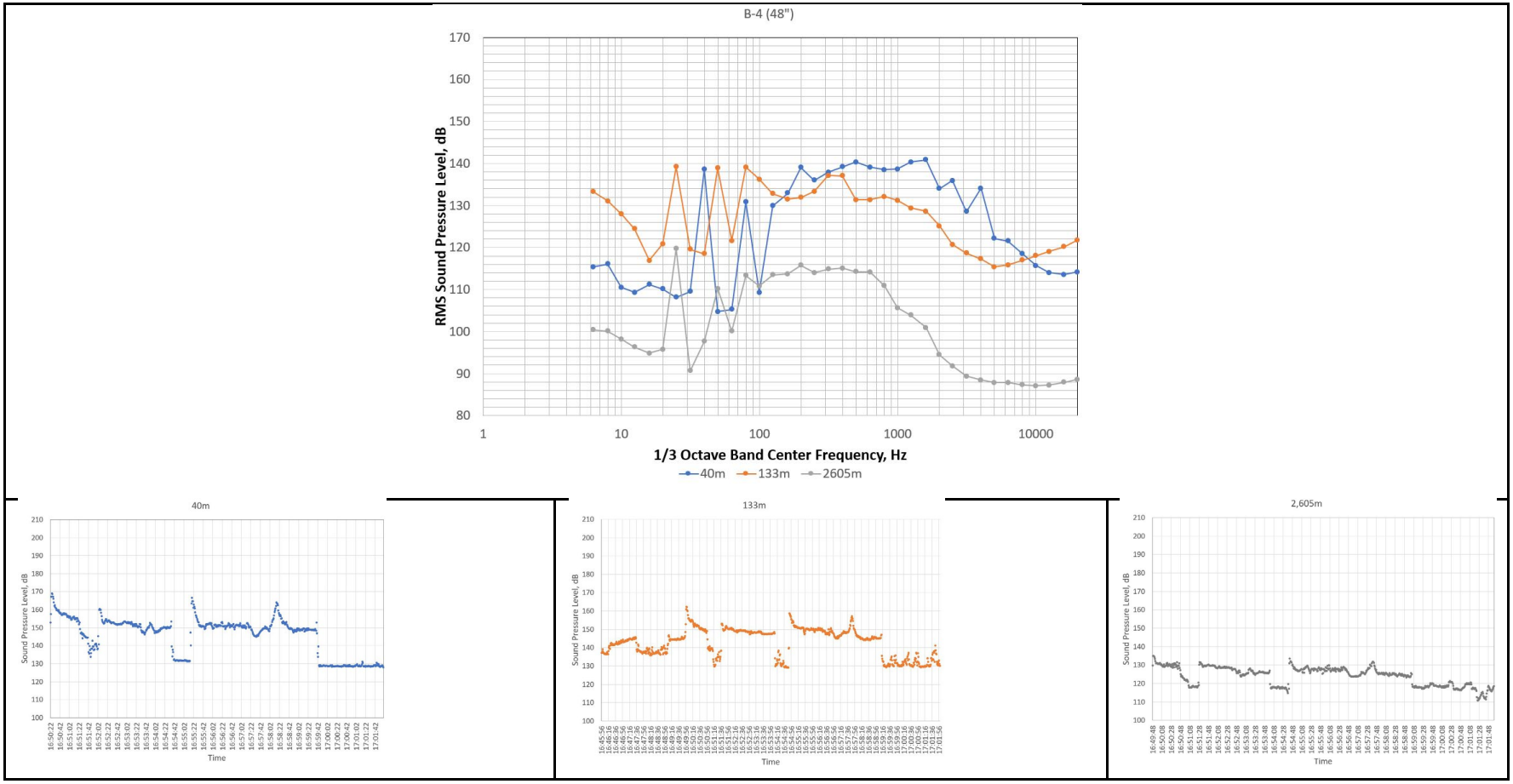


Figure 5-24. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 24, 2020 (Pile B-4)

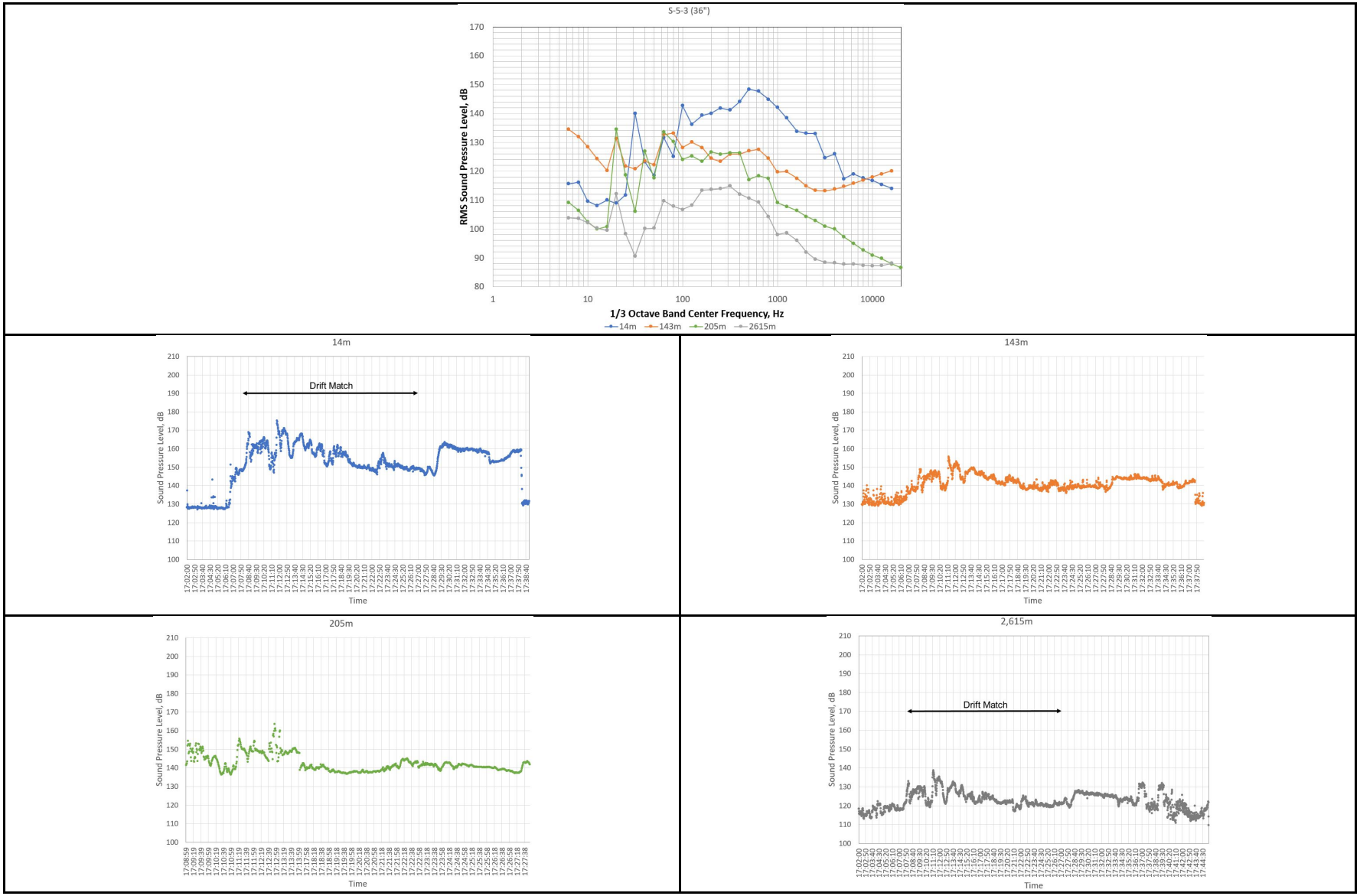


Figure 5-25. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 24, 2020 (Pile S-5)

Table 5-19. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 24, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
14:30 to 14:37	S-3 (24-inch)	13	130	157	157	14.1	158.6	N/A			N/A	N/A
		2,620	115	125	124			N/A				
15:25 to 15:35	S-1 (24-inch)	16	130	155	154	14.2	157.9	130	155	154	14.4	157.7
		553	N/A					120	132	131		
		2,620	115	124	124			115	124	124		
16:47 to 16:59	B-4 (48-inch)	40	130	151	152	13.1	158.9	N/A			N/A	N/A
		2,605	120	128	127			N/A				
17:06 to 17:37	S-5 (36-inch, Bent 1)	14	130	156	156	14.3	158.1	130	155	156	14.4	158.0
		205	N/A					120	141	143		
		2,615	115	124	124			115	123	124		

Table 5-20. Summary of RMS data in the north direction for piles driven on June 24, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
14:30 to 14:37	S-3 (24-inch)	13	130	157	157
		150	135	139	139
15:25 to 15:35	S-1 (24-inch)	16	130	155	154
		159	130	140	139
16:47 to 16:59	B-4 (48-inch)	40	130	151	152
		133	130	149	149
17:06 to 17:37	S-5 (36-inch, Bent 1)	14	130	156	156
		143	130	142	142

5.1.11 June 25, 2020, Measurement Results

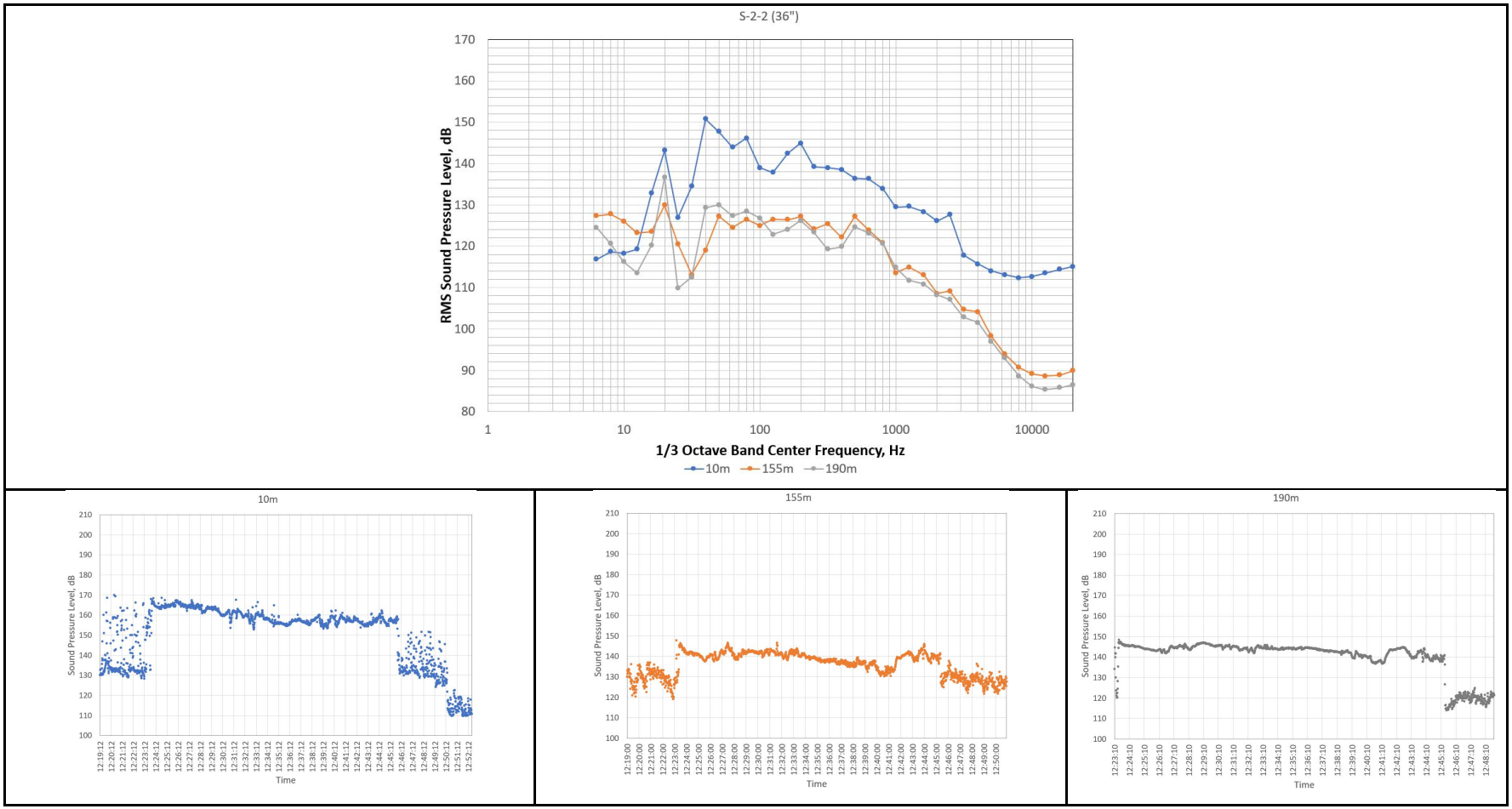


Figure 5-26. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 25, 2020 (Pile S-2)

Table 5-21. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles driven on June 25, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
12:23 to 12:45	S-2 (36-inch, Bent 1)	10	135	159	159	N/A	159.0	N/A			N/A	N/A

Table 5-22. Summary of RMS data in the north direction for piles driven on June 25, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
12:23 to 12:45	S-2 (36-inch, Bent 1)	10	135	159	160
		155	130	140	140
		190	122	144	143

5.2 Summary of Underwater Sound Monitoring Data during Vibratory Air Bubble Casing Installation

5.2.1 June 9, 2020, Measurement Results

One 72-inch air bubble casing (D-1) was installed on June 9, 2020 using a vibratory hammer. Figure 5-27 shows the median RMS spectra for each measurement location, collected during the vibratory driving of the D-1 air bubble casing. Also shown in the figure are the RMS time histories for each monitoring location. Figure 5-23 and Figure 5-24 summarize the maximum, median, and average RMS levels for the pile casing in the east-west direction and north direction, respectively. Transmission loss coefficients calculated for each pile are also shown on Figure 5-23. These calculations were made with all data except the SFD position. Figures and tables showing data for the removal of other air bubble casings are also presented in this section.

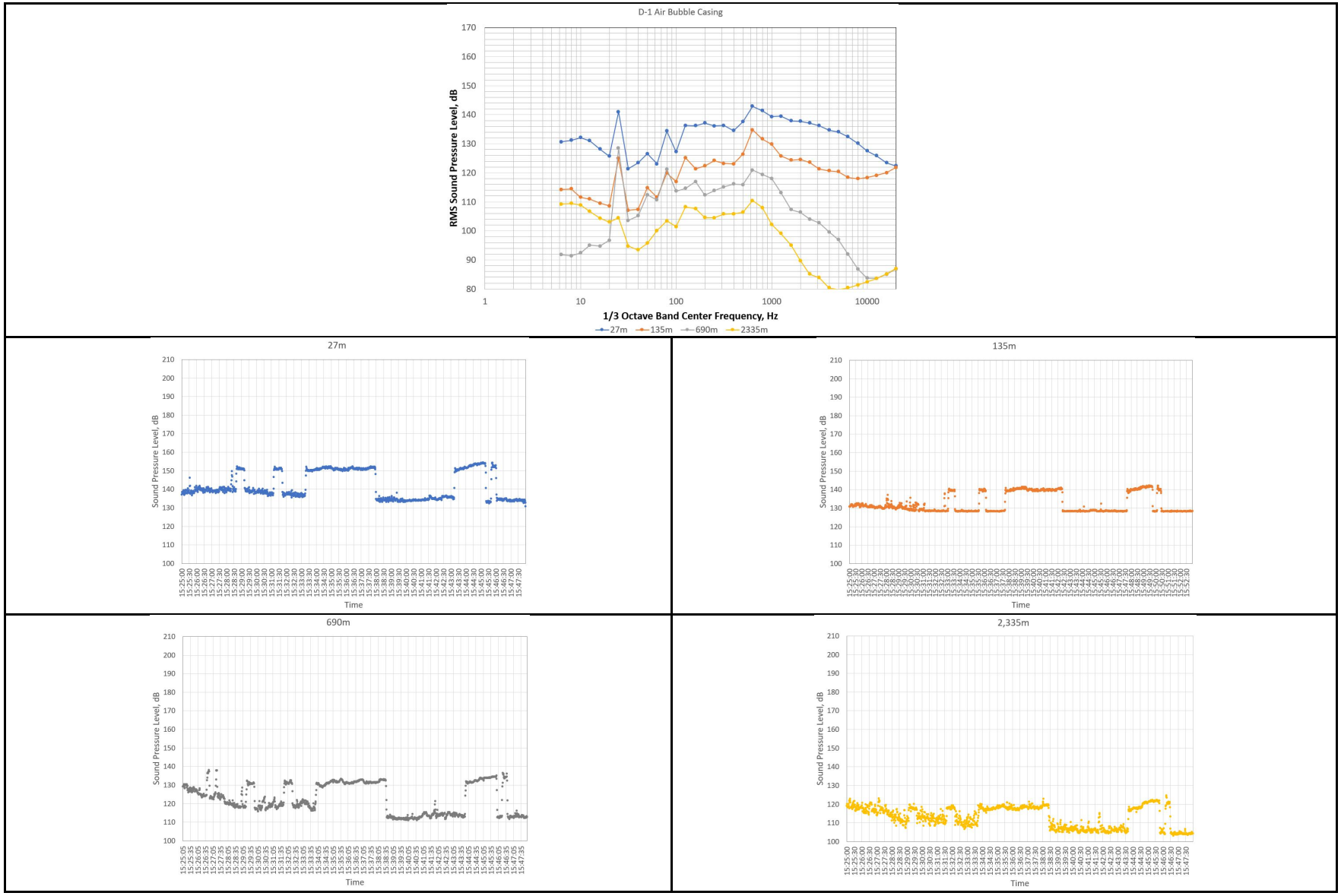


Figure 5-27. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 9, 2020 (D-1 Air Bubble Casing)

Table 5-23. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for pile casings installation on June 9, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
15:28 to 15:47	D-1 Air Bubble Curtain Casing (72-inch)	27	135	151	151	16.6	158.9	N/A			N/A	N/A
		690	115	132	132			N/A				
		2,335	110	118	117			N/A				

Table 5-24. Summary of RMS data in the north direction for pile casings installation on June 9, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
15:28 to 15:47	D-1 Air Bubble Casing (72-inch)	27	135	151	151
		135	130	140	139

5.2.2 June 14, 2020, Measurement Results

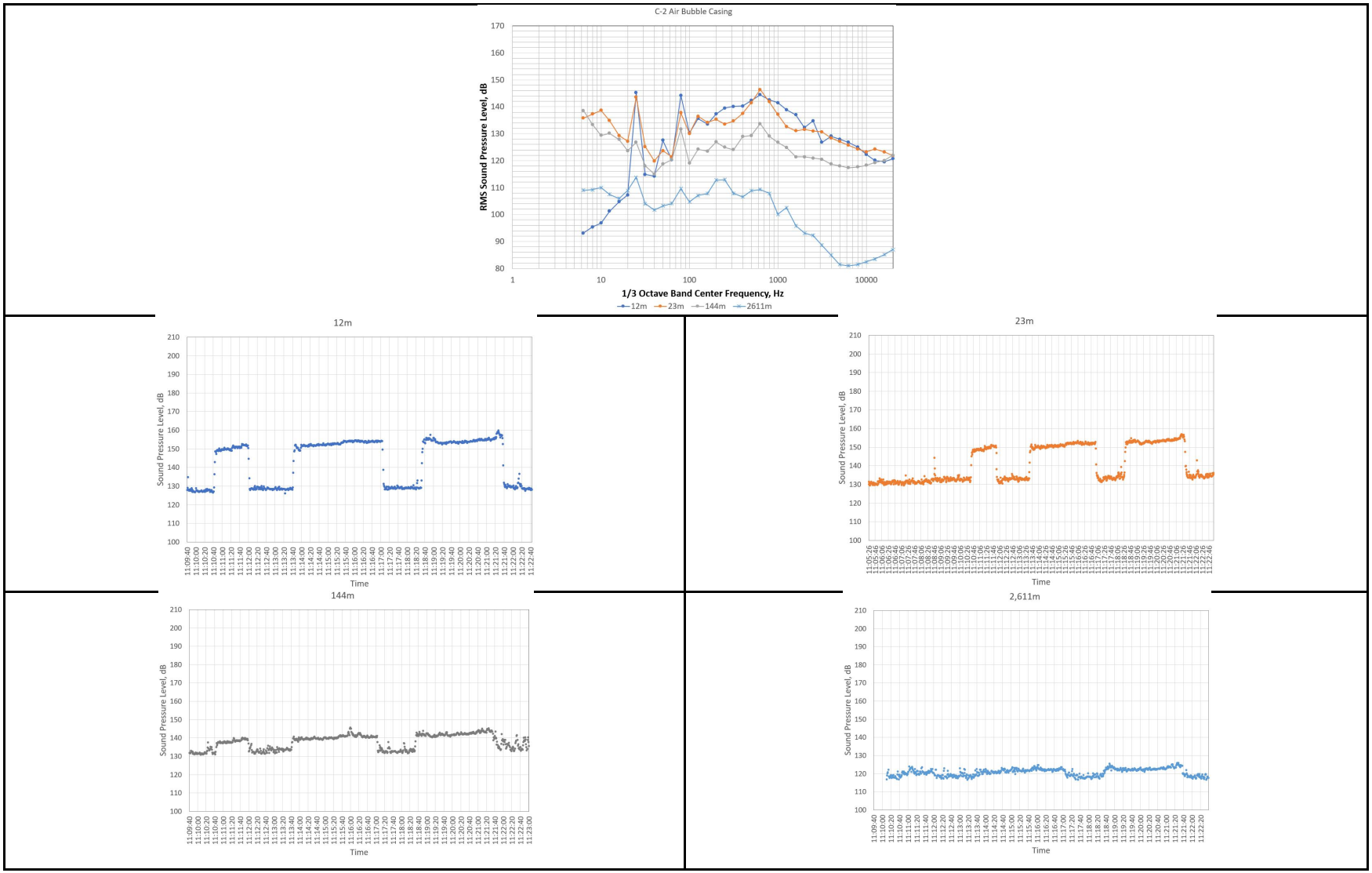


Figure 5-28. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 14, 2020 (C-2 Air Bubble Casing)

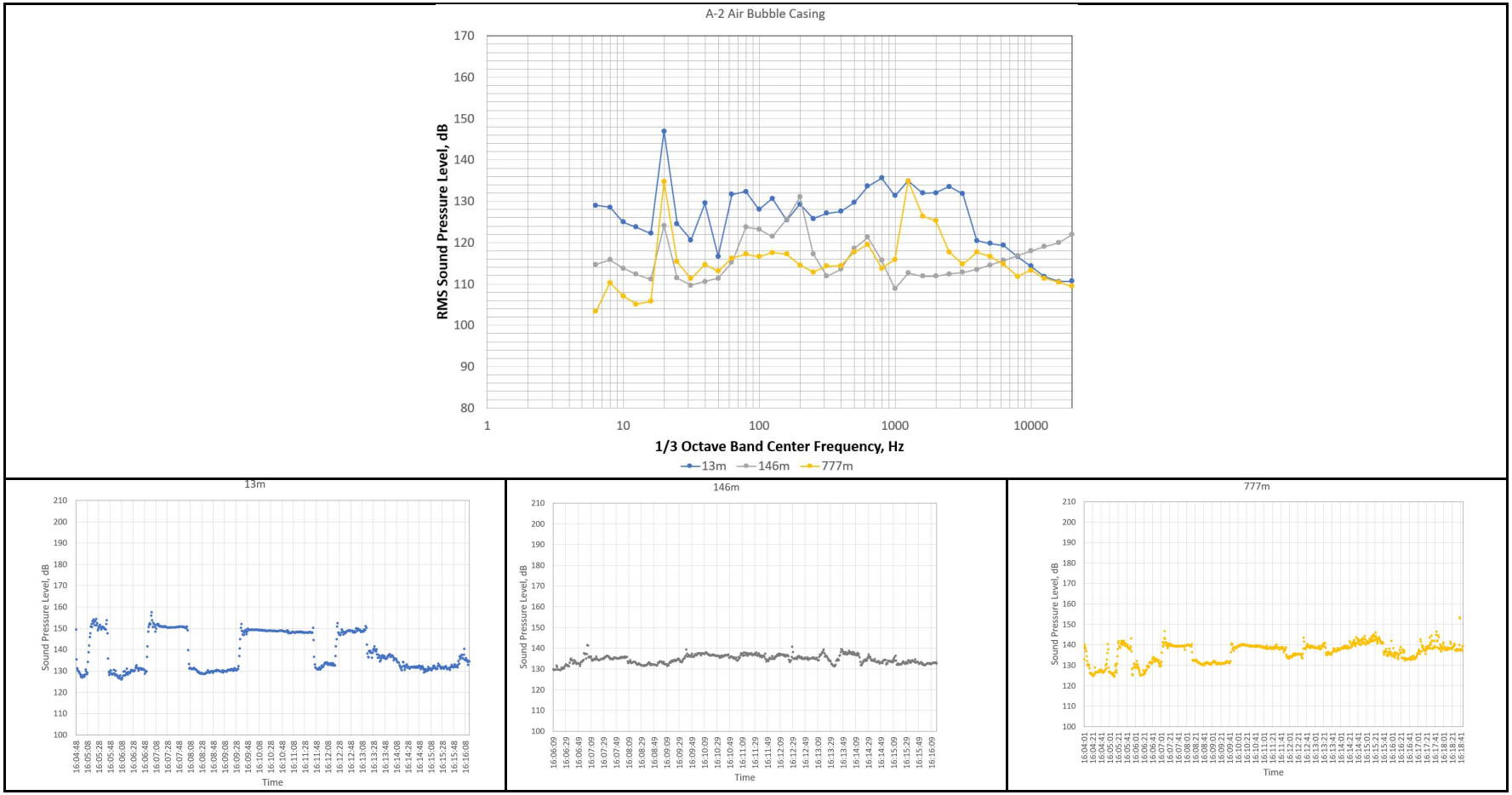


Figure 5-29. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 14, 2020 (A-2 air bubble casing)

Table 5-25. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for pile casings installation on June 14, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
11:12 to 11:21	C-2 Air Bubble Curtain Casing (72-inch)	12	128	154	154	15.4	156.3	N/A			N/A	N/A
		23	135	152	152			N/A				
		2,611	119	122	119			N/A				
16:06 to 16:13	A-2 Air Bubble Curtain Casing (72-inch)	13	132	149	149	6.3	149.6	N/A			N/A	N/A
		777	133	139	138			N/A				

Table 5-26. Summary of RMS data in the north direction for pile casings installation on June 14, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
11:12 to 11:21	C-2 Air Bubble Casing (72-inch)	12	128	154	153
		23	135	152	152
		144	132	141	140
16:06 to 16:13	A-2 Air Bubble Casing (72-inch)	13	154	149	149
		146	130	136	134

5.2.3 June 20, 2020, Measurement Results

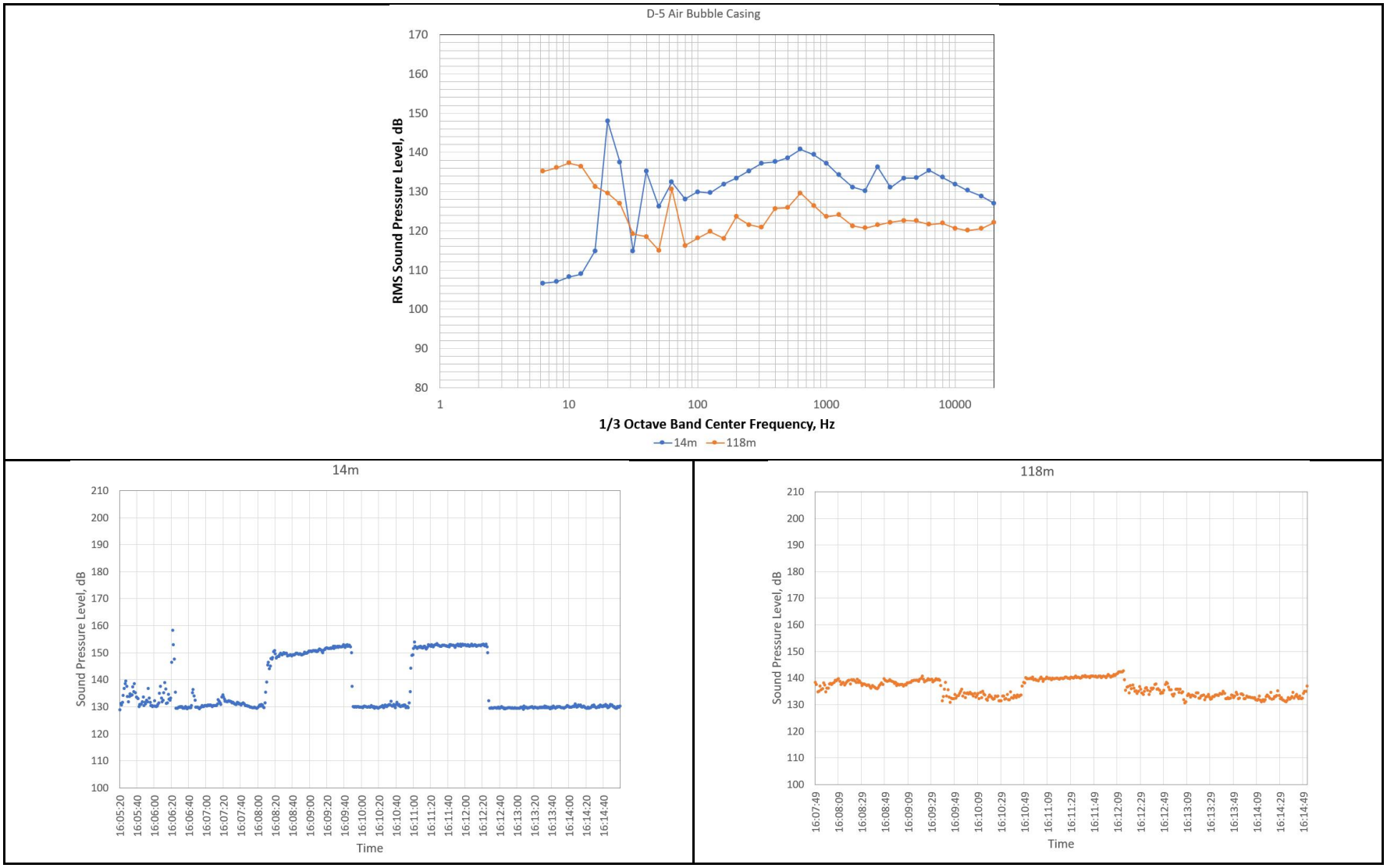


Figure 5-30. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 20, 2020 (D-5 air bubble casing)

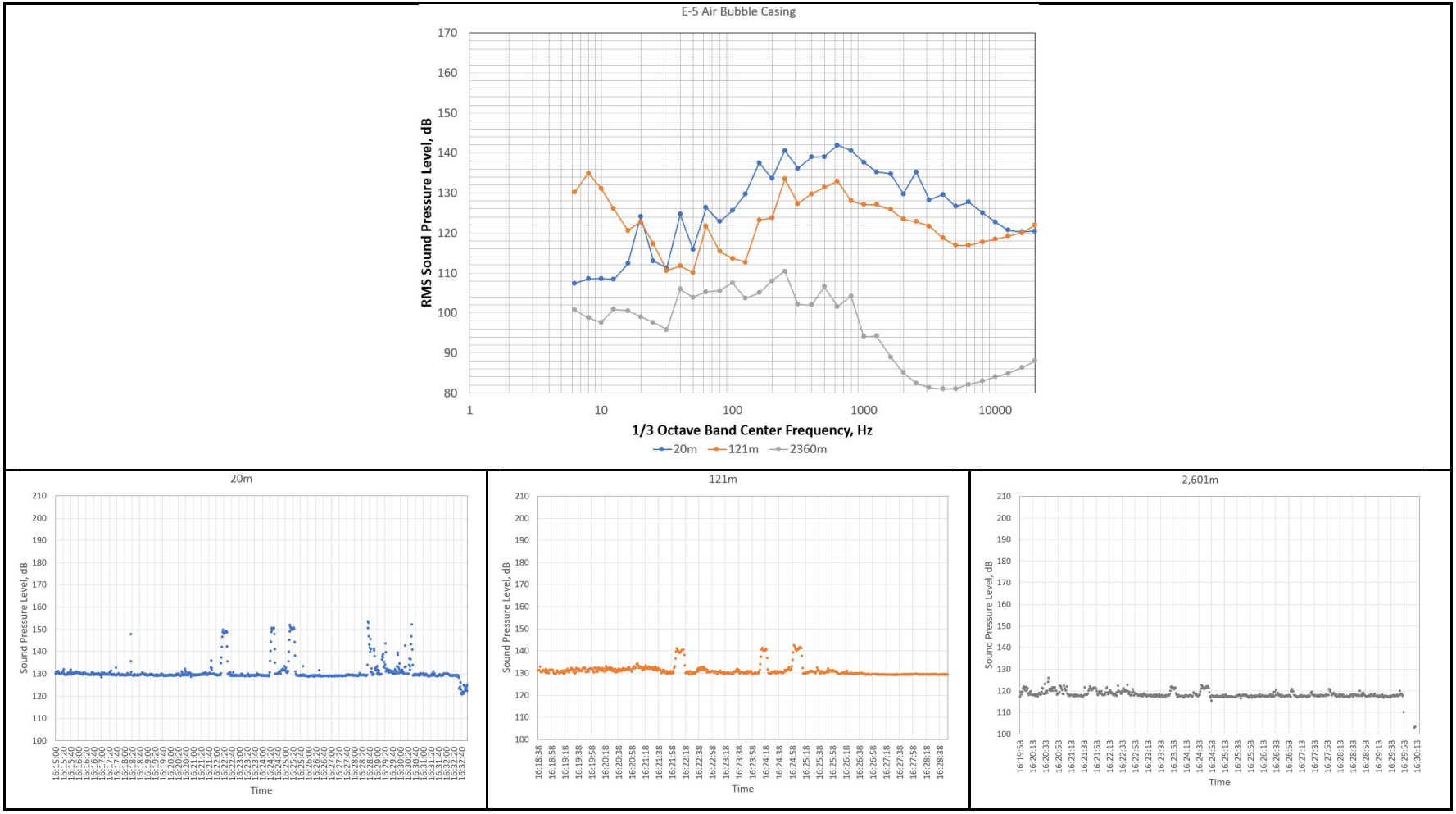


Figure 5-31. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 20, 2020 (E-5 air bubble casing)

Table 5-27. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for pile casings installation on June 20, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
16:09 to 16:12	D-5 Air Bubble Casing (72-inch)	14	130	152	152	15.0 [a]	154.0 [a]	N/A			N/A	N/A
		118	132	139	138			N/A				
16:22 to 16:25	E-5 Air Bubble Casing (72-inch)	20	130	150	150	15.1	154.5	N/A			N/A	N/A
		2,601	118	121	118			N/A				

[a] Calculated using the SFD position since only two monitoring locations were obtained for Casing D-5. Using a transmission loss coefficient of 15Log, the RMS level at 10 meters would be 154.2 dB.

Table 5-28. Summary of RMS data in the north direction for pile casings installation on June 20, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
16:22 to 16:25	E-5 Air Bubble Casing (72-inch)	20	130	150	150
		121	131	141	140

5.3 Summary of Underwater Sound Monitoring Data during Vibratory Removal

5.3.1 June 24, 2020 Measurement Results

One 36-inch pin pile was removed on June 24, 2020, using a vibratory hammer. Figure 5-32 shows the median RMS spectra for each measurement location, collected during the vibratory removal of the pin pile. Also shown in the figure are the RMS time histories for each monitoring location. Table 5-29 and Table 5-30 summarize the maximum, median, and average RMS levels in the east-west and north directions, respectively. Transmission loss coefficients calculated for each pile are also shown in the table. These calculations were made with all data except the SFD position.

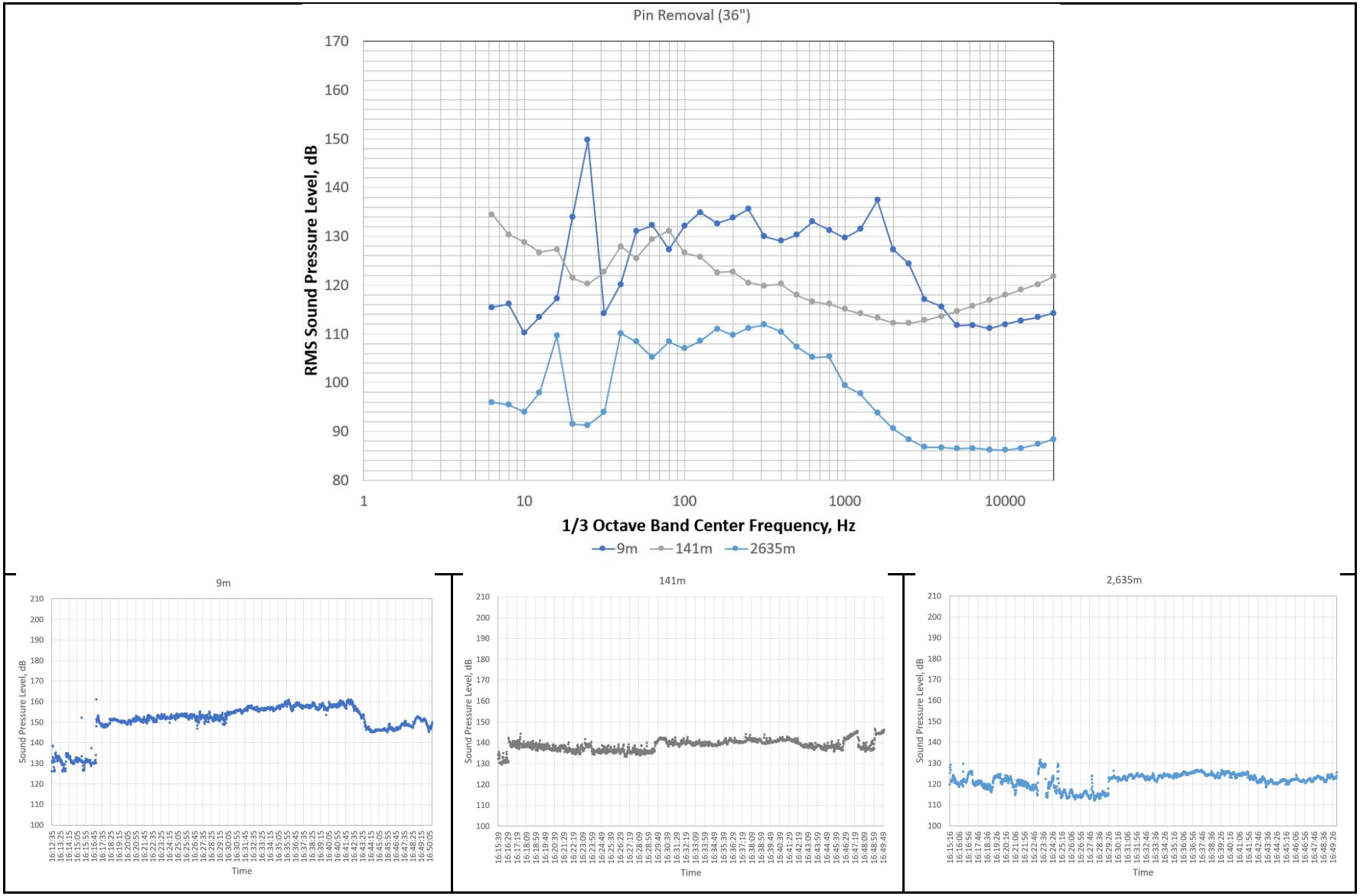


Figure 5-32. One-third-octave band spectra for each monitoring location and the RMS time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 24, 2020 (Pin Pile Removal)

Table 5-29. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles removed on June 24, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)									
			Full Event					Drift Match Segment Only				
			Background	Measured	Project	TL Coefficients	Level at 10 meters	Background	Measured	Project	TL Coefficients	Level at 10 meters
16:16 to 16:52	36" Pin Removal	9	132	153	153	13.1	152.3	N/A			N/A	N/A
		2,635	115	122	121			N/A				

Table 5-30. Summary of RMS data in the north direction for piles removed on June 24, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Background	Measured	Project
16:16 to 16:52	36" Pin Removal	9	132	153	153
		141	133	139	138

5.4 Summary of Underwater Sound Monitoring Data during Impact Pile Driving

5.4.1 June 10, 2020, Measurement Results

Two 48-inch piles (D-1 and A-1) were driven on June 10, 2020, using an impact hammer. Figure 5-33 and Figure 5-34 show the median single-strike SEL spectra for each measurement location of Piles D-1 and A-1, respectively. Also shown in the figure are the single-strike SEL time histories for each monitoring location. Table 5-31 summarizes the maximum, median, and average SEL levels in the east-west direction, as well as the transmission loss coefficients calculated for each pile. Table 5-32 summarizes the maximum, median, and average SEL levels in the north direction. Similar tables and figures follow for impact pile driving on other days.

An air bubble casing was used during the impact installation of all 48-inch piles discussed in this section.

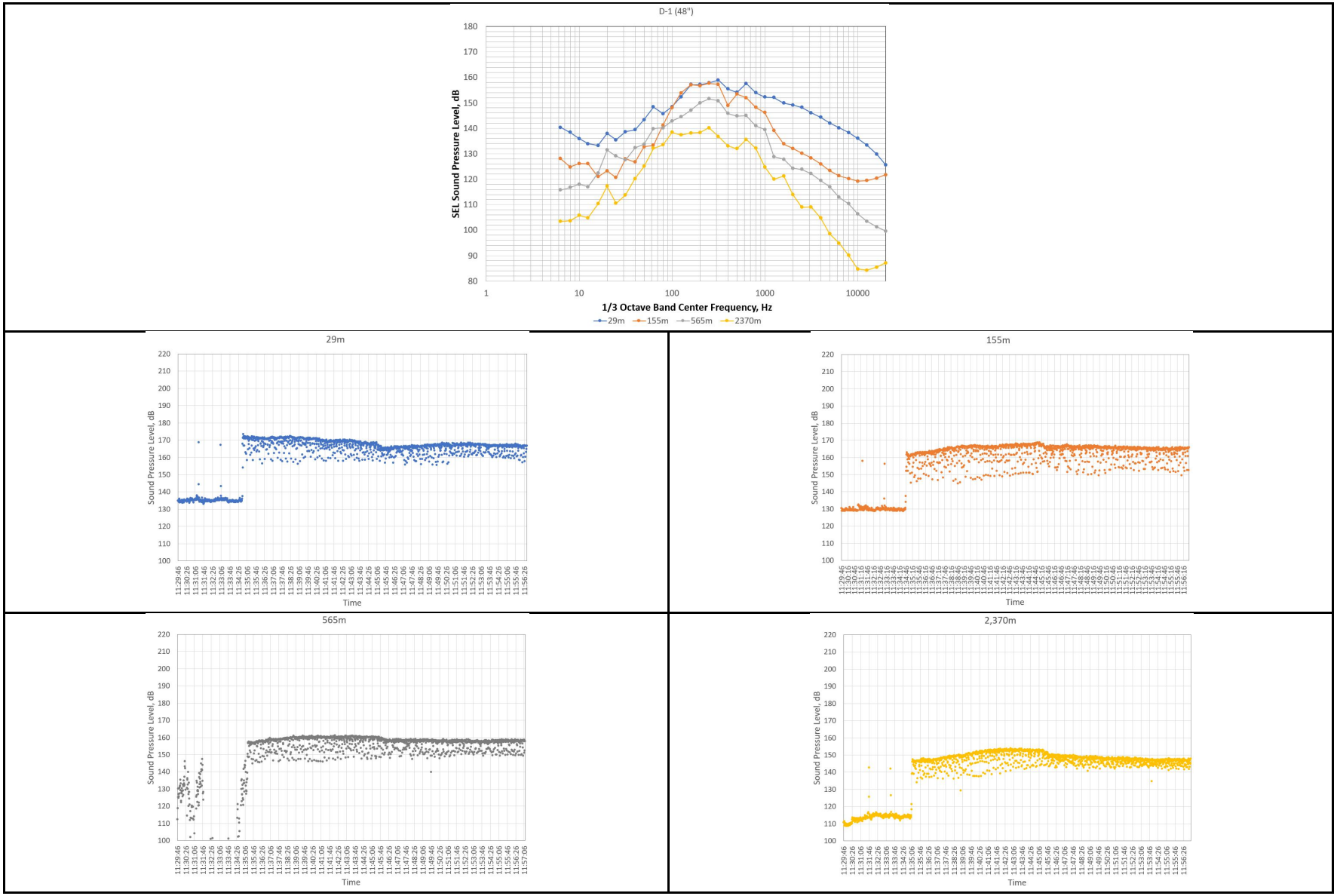


Figure 5-33. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 10, 2020 (Pile D-1)

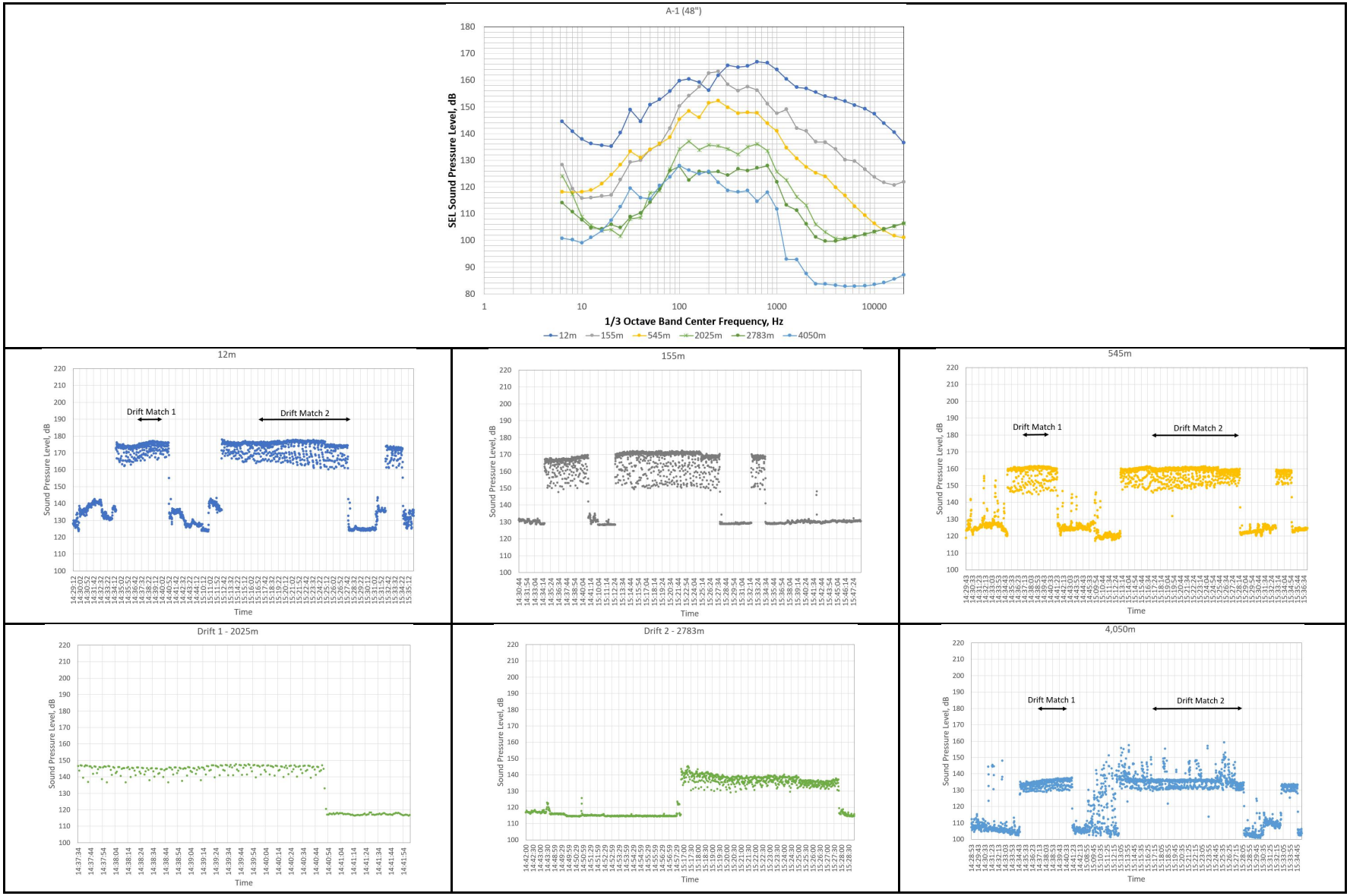


Figure 5-34. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 10, 2020 (Pile A-1)

Table 5-31. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles impacted on June 10, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)														
			Full Event					Drift Match Segment 1 Only					Drift Match Segment 2 Only				
			Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters
11:30 to 11:56	D-1 (48-inch)	29	185	177	178	8.8	182.2	N/A			N/A	N/A	N/A			N/A	N/A
		565	174	170	170			N/A					N/A				
		2,370	164	159	159			N/A					N/A				
14:35 to 15:34	A-1 (48-inch)	12	189	187	186	16.2	191.6	188	187	186	15.5	191.4	189	187	187	16.7	192.0
		545	175	173	173			175	173	173			175	174	173		
		2,025	N/A					159 [a]	157 [a]	157 [a]			N/A				
		2,783	N/A					N/A					157 [a]	149 [a]	149 [a]		
		4,050	150	143	143			145	144	144			150	143	143		

[a] RMS levels reported here were from the SLM meter.

Table 5-32. Summary of RMS data in the north direction for piles impacted on June 10, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Max	Median	Mean
11:30 to 11:56	D-1 (48-inch)	29	185	177	178
		155	179	177	177
14:35 to 15:34	A-1 (48-inch)	12	189	187	186
		155	185	183	183

5.4.2 June 12, 2020, Measurement Results

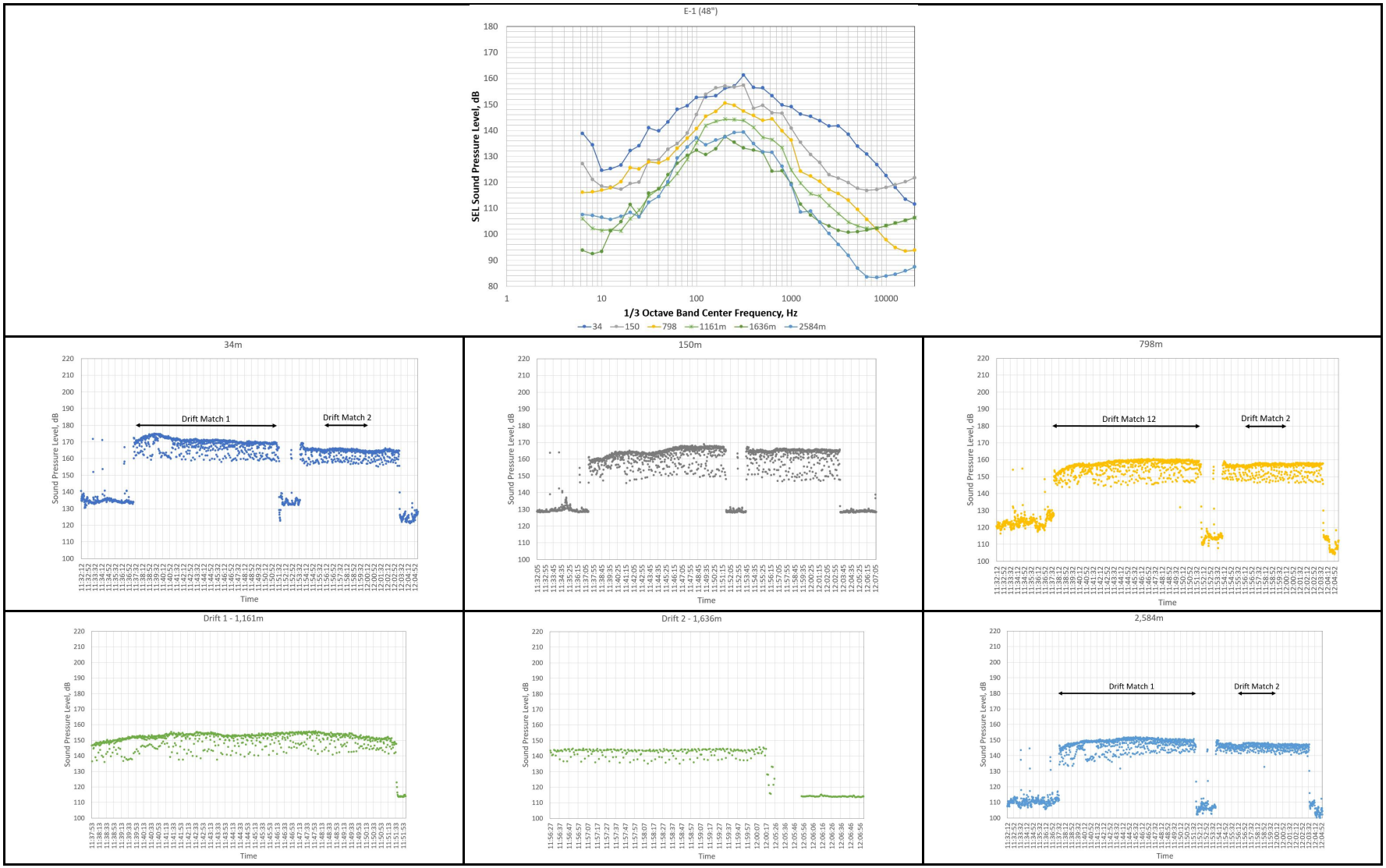


Figure 5-35. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 12, 2020 (Pile E-1)

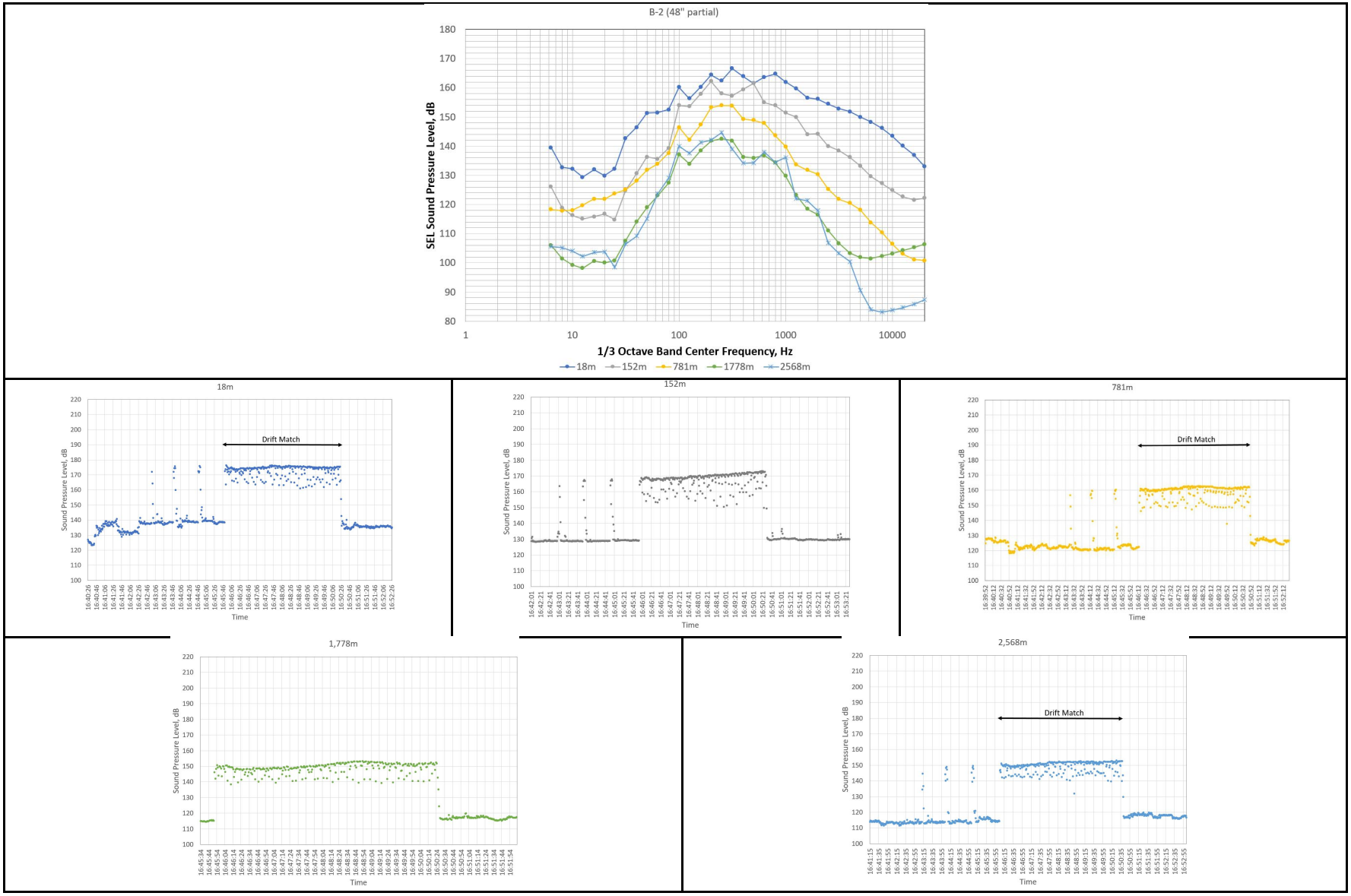


Figure 5-36. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 12, 2020 (Pile B-2 partial)

Table 5-33. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles impacted on June 12, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)														
			Full Event					Drift Match Segment 1 Only					Drift Match Segment 2 Only				
			Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters
11:33 to 12:04	E-1 (48-inch)	34	187	181	180	12.5	186.2	187	183	183	11.8	189.4	176	175	175	9.5	180.6
		798	160	157	157			170	168	168			167	166	166		
		1,161	N/A					167 [a]	164 [a]	164 [a]			N/A				
		1,636	N/A					N/A					168 [a]	155 [a]	155 [a]		
		2,584	164	160	160			164	161	161			160	159	158		
16:42 to 16:51	B-2 (48-inch, partial)	18	187	185	185	10.2	188.1	187	185	185	11.1	188.5	N/A			N/A	N/A
		781	173	171	171			173	171	171			N/A				
		1,778	N/A					164 [a]	160 [a]	160 [a]			N/A				
		2,568	163	162	161			163	162	161			N/A				

[a] RMS levels reported here were from the SLM meter.

Table 5-34. Summary of RMS data in the north direction for piles impacted on June 12, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Max	Median	Mean
11:33 to 12:04	E-1 (48-inch)	34	187	181	180
		150	181	179	178
16:42 to 16:51	B-2 (48-inch, partial)	18	187	185	185
		152	185	181	181

5.4.3 June 14, 2020, Measurement Results

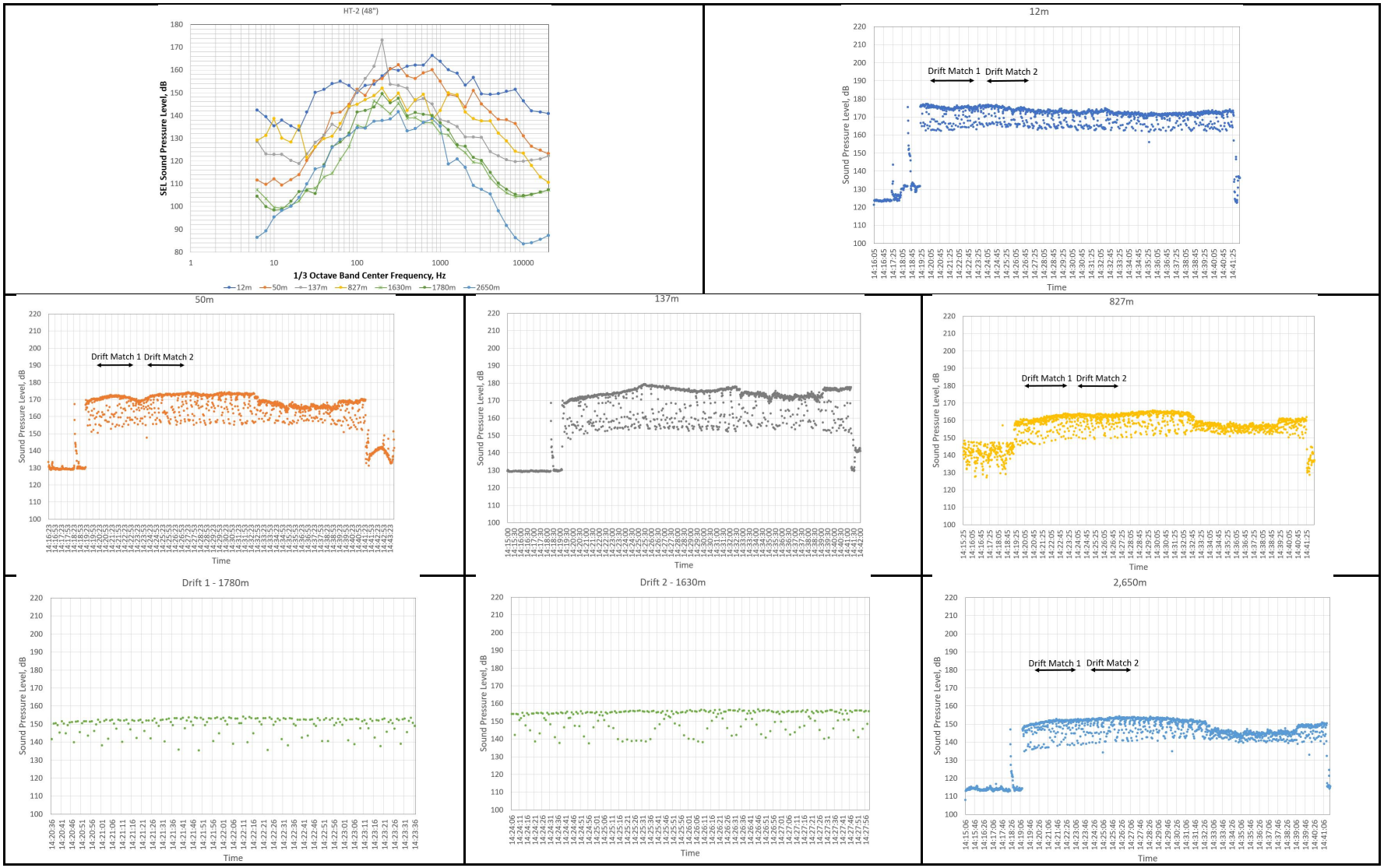


Figure 5-37. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 14, 2020 (Pile HT-2)

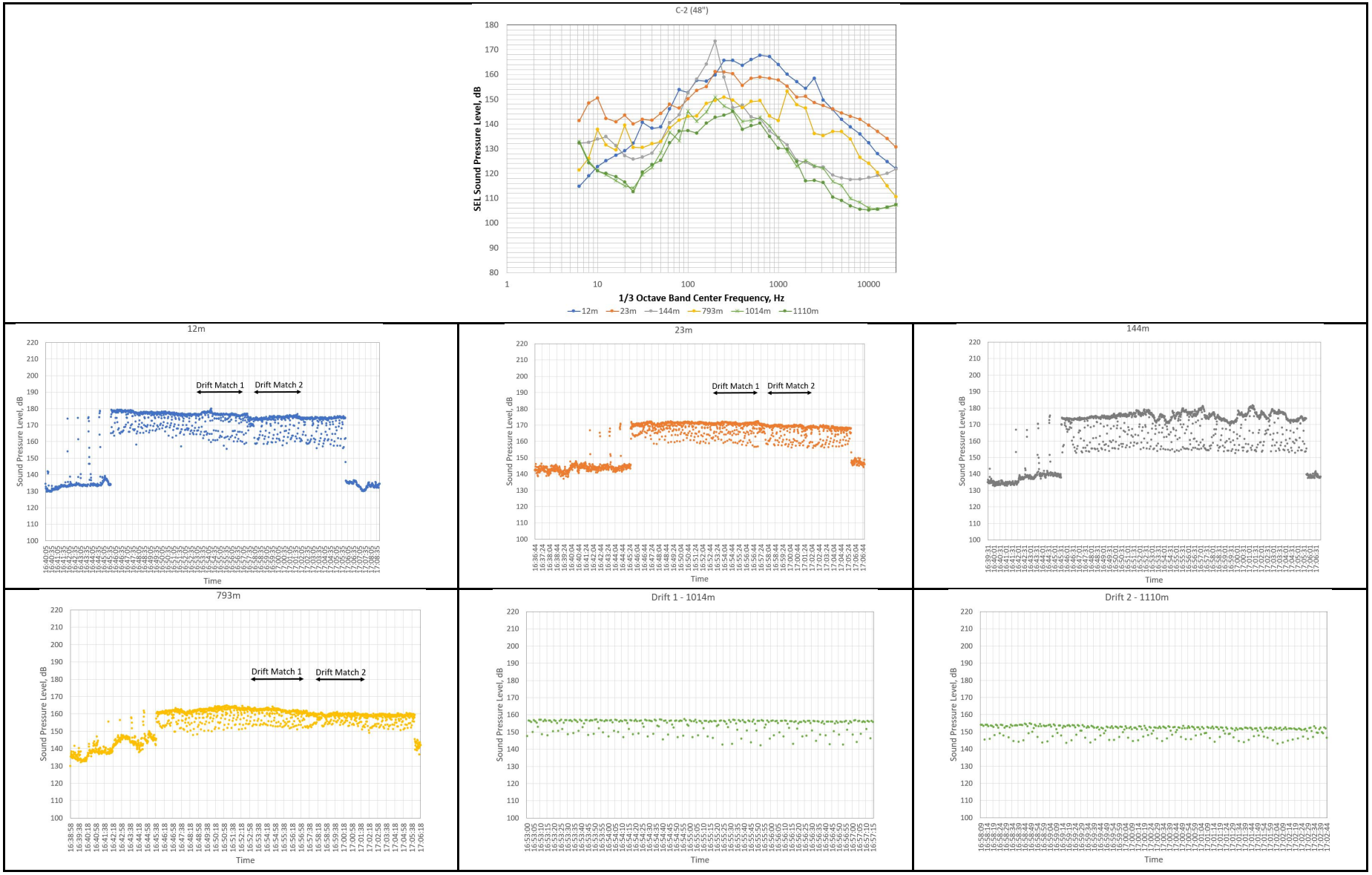


Figure 5-38. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 14, 2020 (Pile C-2)

Table 5-35. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles impacted on June 14, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)														
			Full Event					Drift Match Segment 1 Only					Drift Match Segment 2 Only				
			Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters
14:18 to 14:41	HT-2 (48-inch)	12	189	185	185	9.6	187.3	188	186	186	10.4	188.5	188	186	186	9.8	189.1
		50	186	182	182			186[a]	183 [a]	183 [a]			186 [a]	185 [a]	184 [a]		
		827	177	171	171			174	171	171			176	173	173		
		1,780	N/A					164	163	163			N/A				
		1,630	N/A					N/A					166	165	165		
		2,650	165	162	161			164	163	163			165	165	165		
16:41 to 17:05	C-2 (48-inch)	12	192	188	188	8.6	187.1	192	188	188	10.0	187.4	188	185	185	10.5	185.0
		23	184	182	181			184 [a]	182 [a]	182 [a]			182 [a]	180 [a]	180 [a]		
		793	175	171	170			173	170	170			170	168	168		
		1,014	N/A					167	166	166			N/A				
		1,110	N/A					N/A					164	161	162		

[a] RMS levels reported here were from the SLM meter.

Table 5-36. Summary of RMS data in the north direction for piles impacted on June 14, 2020

Time	Pile ID	Distance to Pile from Hydrophone (m)	RMS (dB) Full Event		
			Max	Median	Mean
14:18 to 14:41	HT-2 (48-inch)	12	189	185	185
		50	186	182	182
		137	191	186	187
16:41 to 17:05	C-2 (48-inch)	12	192	188	188
		23	184	182	181
		144	197	187	188

5.4.4 June 16, 2020, Measurement Results

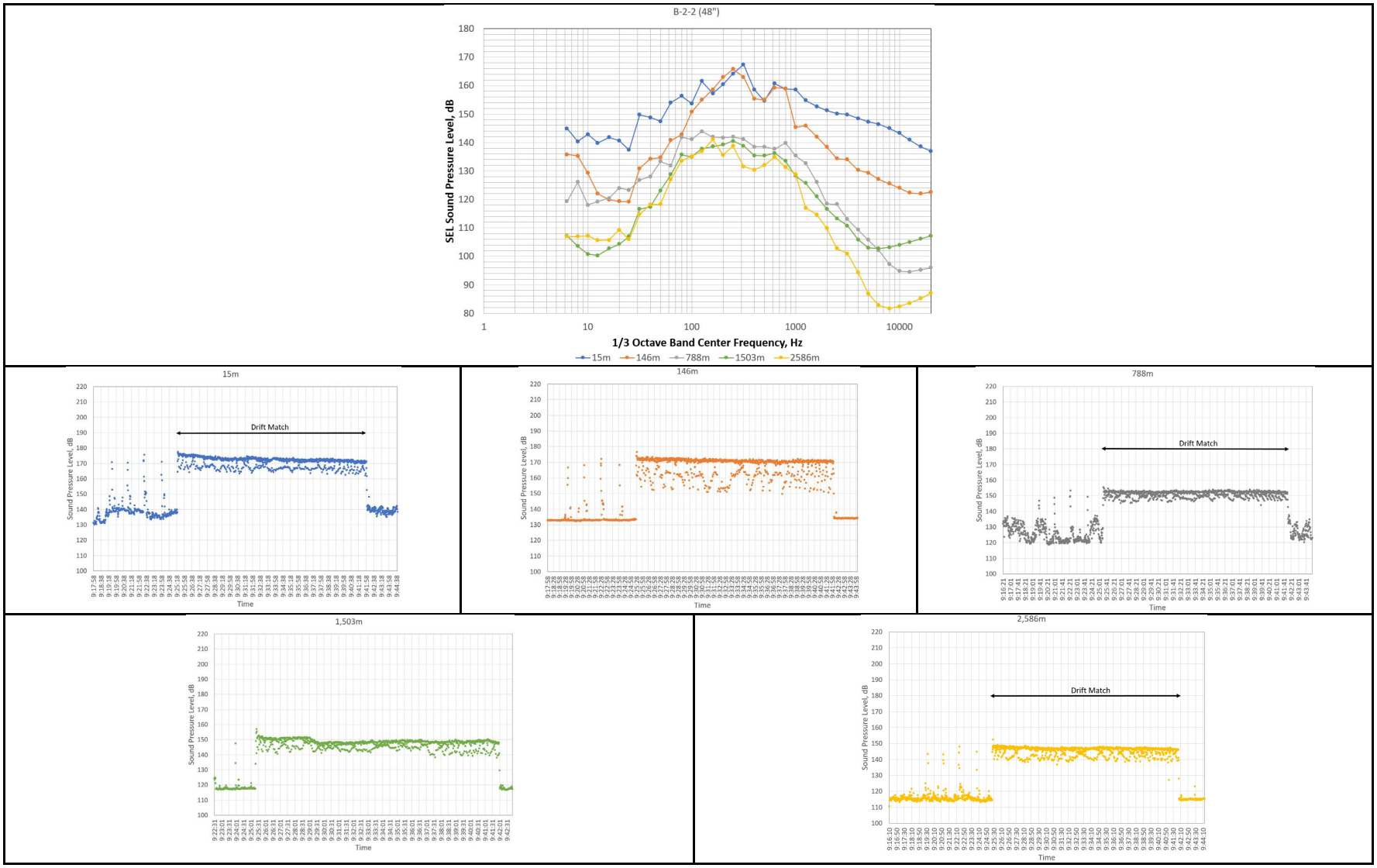


Figure 5-39. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 16, 2020 (Pile B-2)

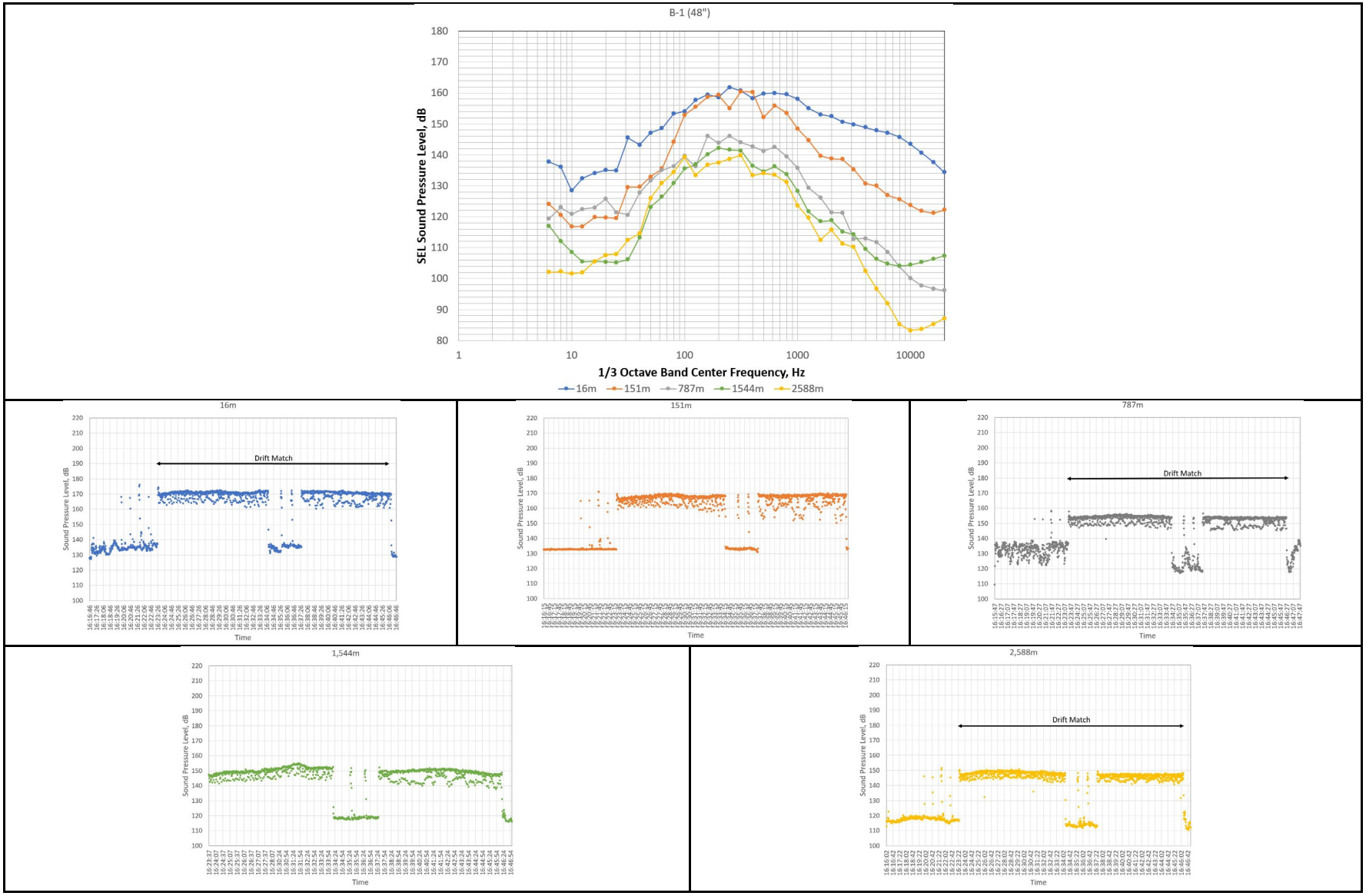


Figure 5-40. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 16, 2020 (Pile B-1)

Table 5-37. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles impacted on June 16, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)														
			Full Event					Drift Match Segment 1 Only					Drift Match Segment 2 Only				
			Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters
9:18 to 9:42	B-2 (48-inch)	15	189	182	182	10.9	183.7	189	182	182	11.3	183.8	N/A			N/A	N/A
		788	167	162	162			167	162	162			N/A				
		1,503	N/A					171	158	158			N/A				
		2,586	164	158	158			164	158	158			N/A				
16:19 to 16:46	B-1 (48-inch)	16	186	181	181	10.3	183.2	186	181	181	10.6	183.3	N/A			N/A	N/A
		787	168	164	164			168	164	164			N/A				
		1,544	N/A					174	159	159			N/A				
		2,588	161	158	158			161	158	158			N/A				

Table 5-38. Summary of RMS data in the north direction for piles impacted on June 16, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Max	Median	Mean
9:18 to 9:42	B-2 (48-inch)	15	189	182	182
		146	189	186	185
16:19 to 16:46	B-1 (48-inch)	16	186	181	181
		151	179	176	176

5.4.5 June 19, 2020, Measurement Results

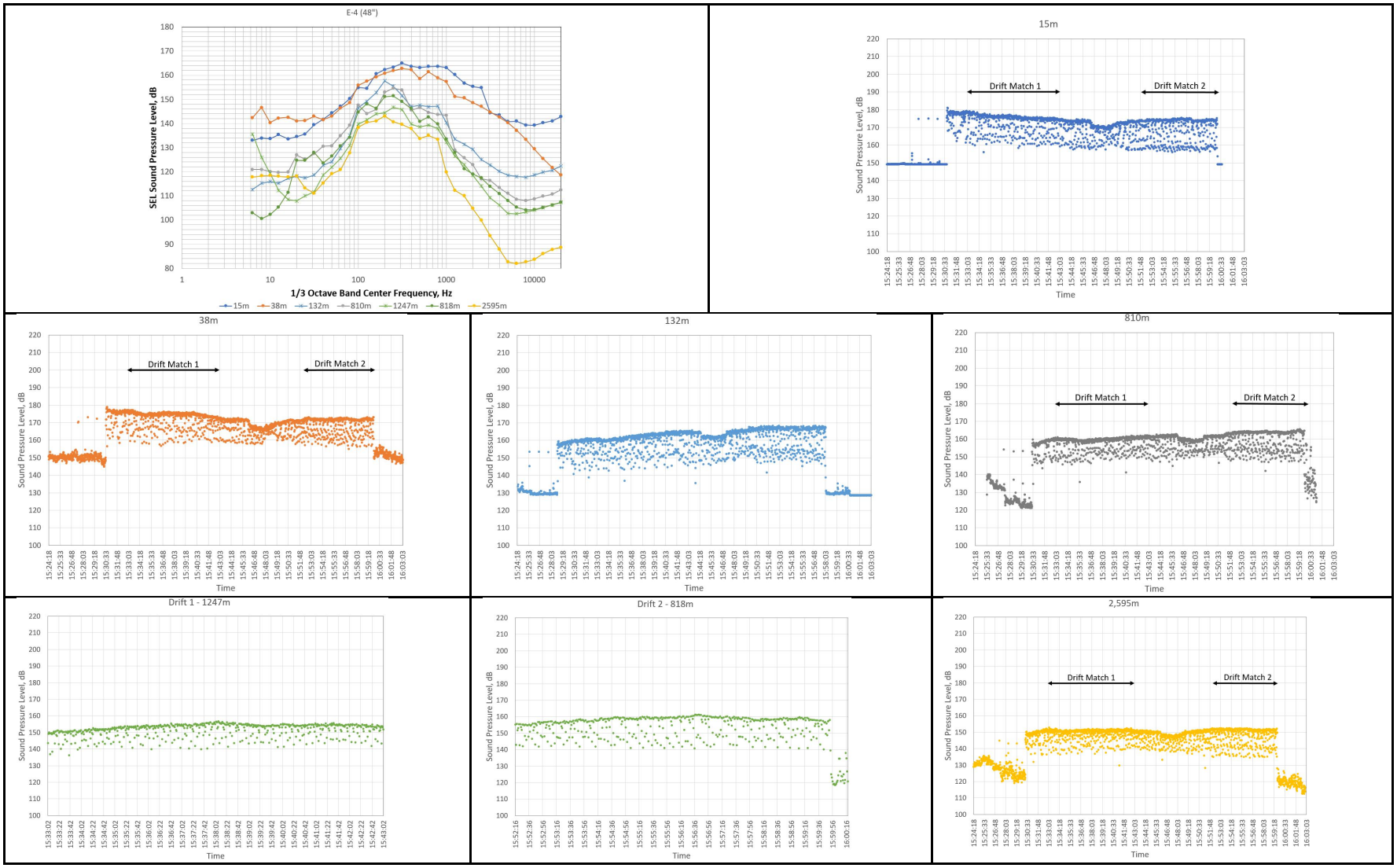


Figure 5-41. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 19, 2020 (Pile E-4)

Table 5-39. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles impacted on June 19, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)														
			Full Event					Drift Match Segment 1 Only					Drift Match Segment 2 Only				
			Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters
15:18 to 16:00	E-4 (48-inch)	15	195	186	187	10.4	189.5	191	188	188	12.8	193.0	187	186	186	9.8	189.0
		38	192	185	185			190	189	188			185	184	184		
		810	176	171	171			172	170	170			176	174	174		
		1,247	N/A					173	163	162			N/A				
		818	N/A					N/A					172	169	168		
		2,595	164	163	162			164	163	163			164	163	163		

Table 5-40. Summary of RMS data in the north direction for piles impacted on June 19, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Max	Median	Mean
15:18 to 16:00	E-4 (48-inch)	15	195	186	187
		38	192	185	185
		132	184	180	179

5.4.6 June 20, 2020, Measurement Results

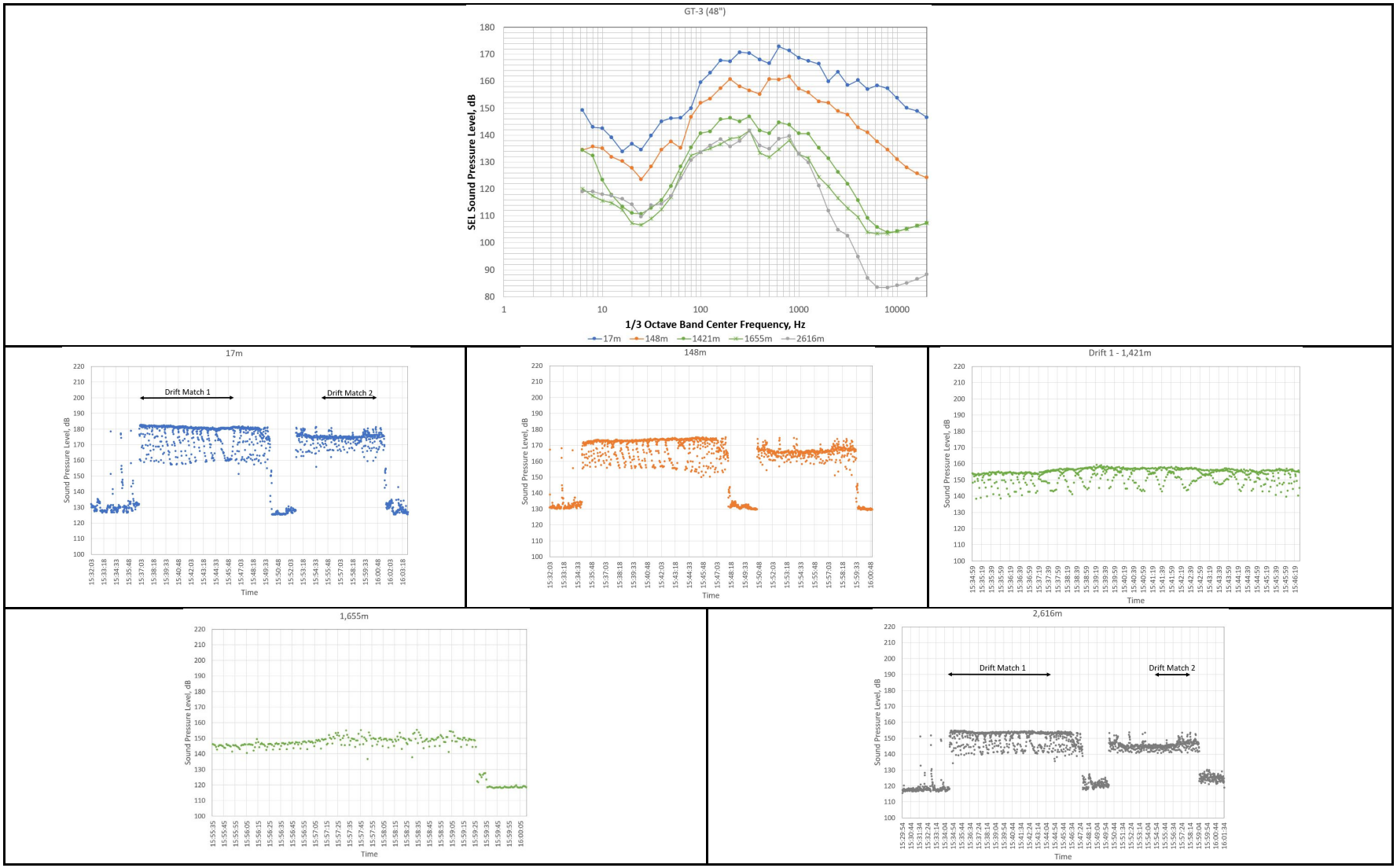


Figure 5-42. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 20, 2020 (Pile GT-3)

Table 5-41. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles impacted on June 20, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)														
			Full Event					Drift Match Segment 1 Only					Drift Match Segment 2 Only				
			Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters
15:32 to 16:00	GT-3 (48-inch)	17	195	192	191	12.8	195.0	195	193	193	13.4	195.9	194	188	189	14.8	191.4
		1,421	N/A					173	165	165			N/A				
		1,655	N/A					N/A					174	158	158		
		2,616	167	164	161			164	156	157			165	163	163		

Table 5-42. Summary of RMS data in the north direction for piles impacted on June 20, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Max	Median	Mean
15:32 to 16:00	GT-3 (48-inch)	17	195	192	191
		148	184	179	178

5.4.7 June 23, 2020, Measurement Results

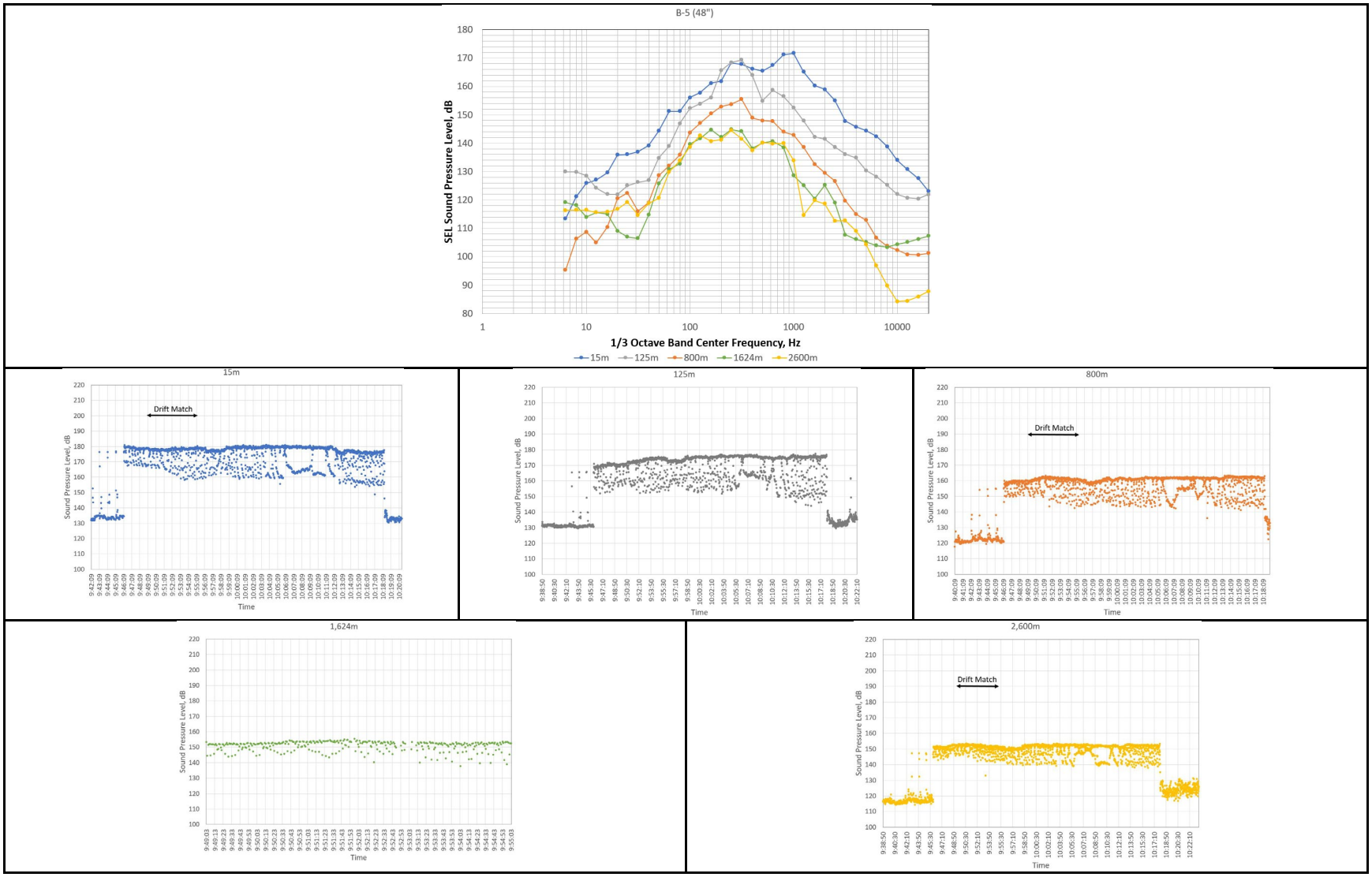


Figure 5-43. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 23, 2020 (Pile B-5)

Table 5-43. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles impacted on June 23, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)														
			Full Event					Drift Match Segment 1 Only					Drift Match Segment 2 Only				
			Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters
9:43 to 10:18	B-5 (48-inch)	15	194	191	191	12.1	193.5	192	190	190	12.7	192.8	N/A			N/A	N/A
		800	179	172	172			174	173	172			N/A				
		1,624	N/A					172	160	160			N/A				
		2,600	165	163	163			165	163	163			N/A				

Table 5-44. Summary of RMS data in the north direction for piles impacted on June 23, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Max	Median	Mean
9:43 to 10:18	B-5 (48-inch)	15	194	191	191
		125	190	187	186

5.4.8 June 24, 2020, Measurement Results

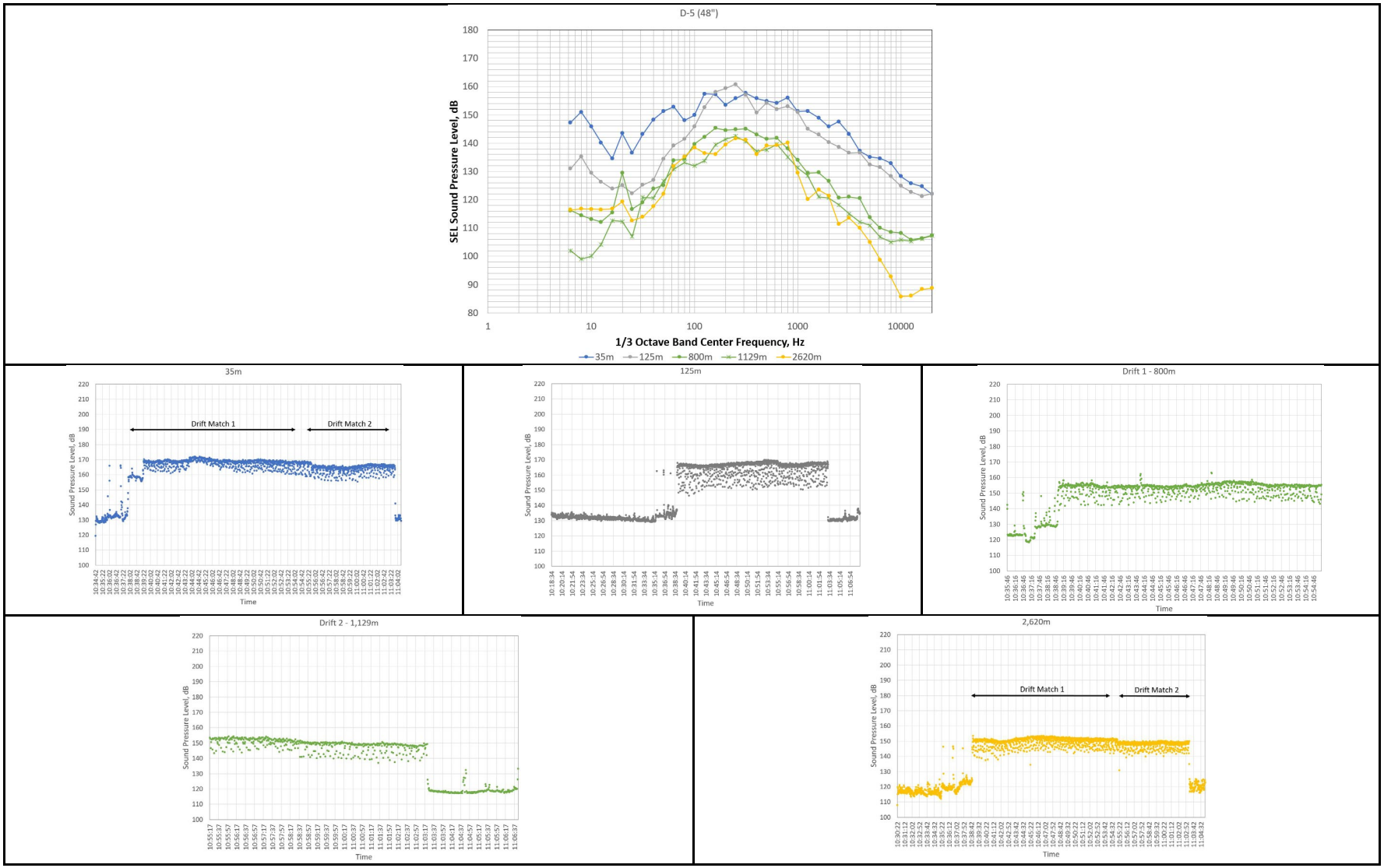


Figure 5-44. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 24, 2020 (Pile D-5)

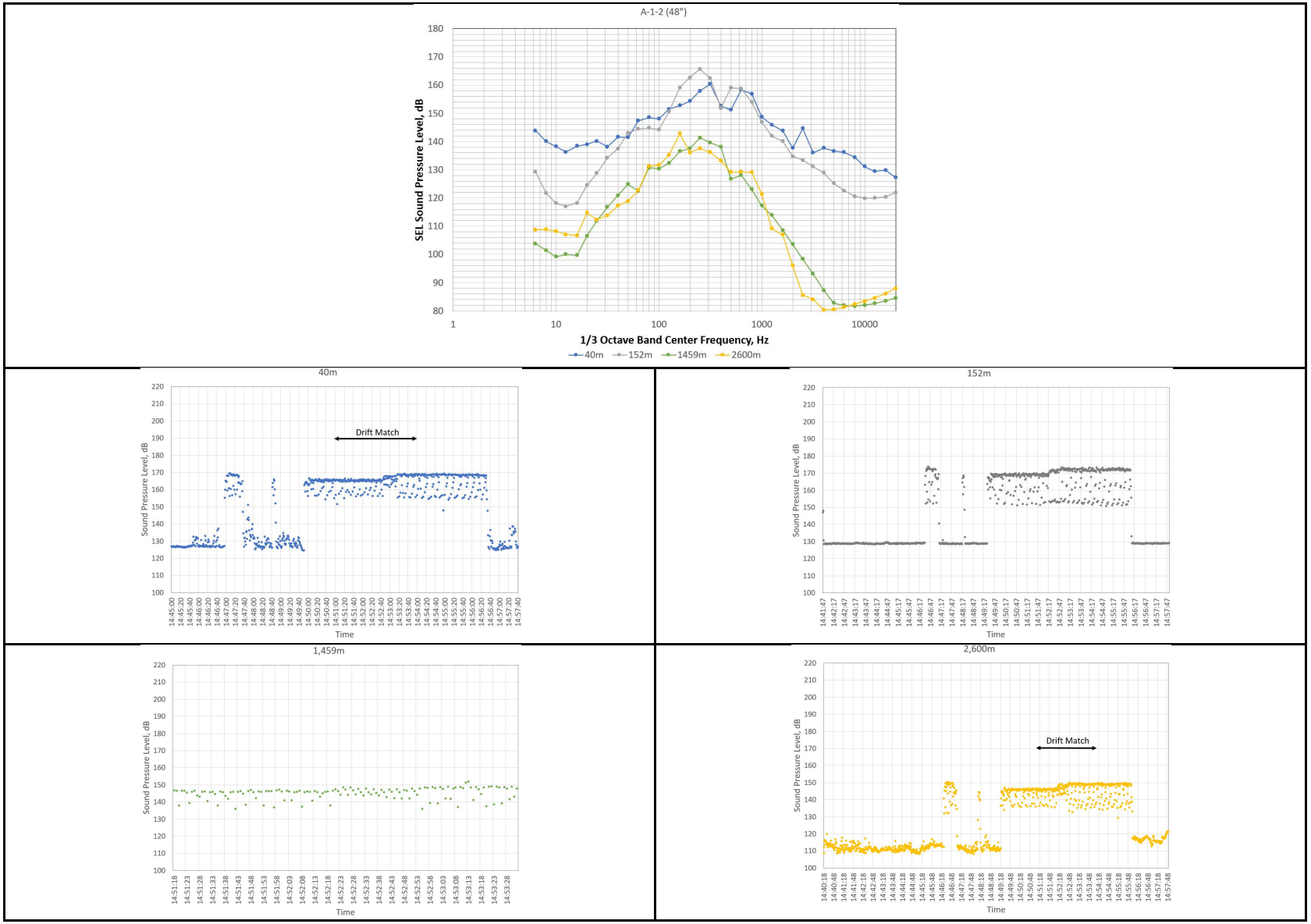


Figure 5-45. One-third-octave band spectra for each monitoring location and the single-strike SEL time histories, summed from 20 to 20,000 Hz, for each monitoring location on June 24, 2020 (Pile A-1)

Table 5-45. Summary of RMS data in the east-west direction, transmission loss coefficients, and estimated RMS level at 10 meters for piles impacted on June 24, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB)														
			Full Event					Drift Match Segment 1 Only					Drift Match Segment 2 Only				
			Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters	Max	Median	Mean	TL Coeff.	Level at 10 meters
10:35 to 11:03	D-5 (48-inch)	35	188	177	177	8.0	181.4	188	178	178	8.5	182.1	178	173	174	7.0	176.8
		800	N/A					173	164	164			N/A				
		1,129	N/A					N/A					168	162	161		
		2,620	166	162	162			166	163	163			162	160	160		
14:46 to 14:56	A-1 (48-inch)	40	180	178	178	10.5	184.3	180	176	177	10.8	182.0	N/A			N/A	N/A
		1,459	N/A					152	147	146			N/A				
		2,600	150	146	146			150	146	146			N/A				

Table 5-46. Summary of RMS data in the north direction for piles impacted on June 24, 2020

Time	Pile ID	Distance to Pile from Hydrophone (meters)	RMS (dB) Full Event		
			Max	Median	Mean
10:35 to 11:03	D-5 (48-inch)	35	188	177	177
		125	178	175	175
14:46 to 14:56	A-1 (48-inch)	40	180	178	178
		152	185	182	81

NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

6. Discussion

6.1 Thirty-six-inch Vibratory Pile Driving Propagation and Threshold Distances, with Bubble Casing

6.1.1 Unweighted Transmission Loss and Distances to the Level B Threshold

Five 36-inch temporary trestle piles were installed with a bubble casing during 2020, with driving times ranging from 22.1 to 36.4 minutes. All 36-inch temporary trestle piles were driven using an APE 300-6 vibratory hammer. Using the drift data, where available, 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 the individual temporary trestle piles. The data points and trendlines for each individual pile are shown on Figure 6-1.

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

Pile ID	Date	Duration of Drive	Transmission Loss Coefficient	R^2 Value	Computed RMS Level at 10 meters	Distance to Level B Threshold (122.2 dB)
S-5 (Bent 3)	6/9/2020	25.6 minutes	14.9	0.974	166	8.6 km
S-5 (Bent 2)	6/16/2020	36.4 minutes	14.7	0.964	161	4.4 km
S-2 (Bent 2)	6/17/2020	36.0 minutes	17.2	0.995	168	4.4 km
S-5 (Bent 1)	6/24/2020	31.5 minutes	14.4	0.990	158	3.1 km
S-2 (Bent 1)	6/25/2020	22.1 minutes	--[a]	--	159	--[a]
	Mean:	**30.3 minutes**	**15.3**	**0.9871**	**162**	**5.1 km**
	Regression Using All Points:		**14.3**	**0.9341**	**161**	**5.7 km**
	Using Far Field Points Only:		**14.9**	**0.8009**	**162**	**5.0 km**

[a] Only measurement conducted at 10 meters.

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 for the 36-inch temporary trestle piles.

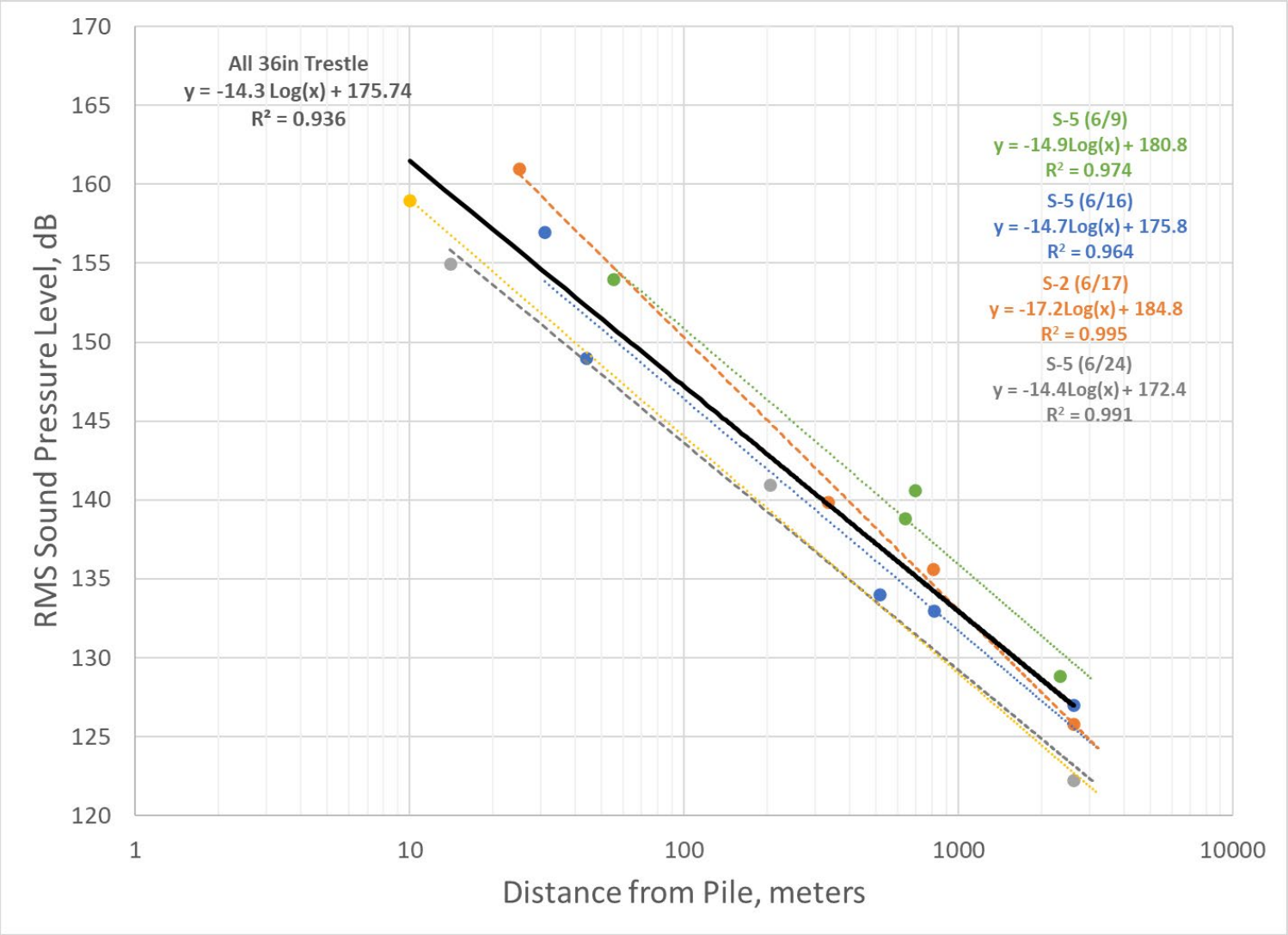


Figure 6-1. Data points and trendlines for all 36-inch temporary trestle piles installed with vibratory hammer and bubble casing

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

	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
Pile ID	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 199 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 198 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 173 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 201 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 219 dB**
S-5 (Bent 3)	15.1	0.9964	195	5m	22.1	0.9529	180	2m	21.8	0.9213	175	12	18.6	0.9891	192	3m	17.8	0.9930	191	<1m
S-5 (Bent 2)	15.9	0.9712	192	3m	16.3	0.9414	169	<1m	15.4	0.9169	164	3	16.6	0.9793	185	1m	16.5	0.9796	185	<1m
S-2 (Bent 2)	18.5	0.9922	198	8m	20.0	0.9819	174	<1m	18.6	0.9709	168	5	20.8	0.9856	191	3m	20.2	0.9879	191	<1m
S-5 (Bent 1)	14.6	0.9996	185	1m	13.1	0.7001	162	<1m	12.2	0.6298	158	<1m	16.8	0.9829	178	<1m	16.0	0.9846	178	<1m
S-2 (Bent 1)	15.0[a]	1.0[a]	180	<1m	15.0[a]	1.0[a]	152	<1m	15.0[a]	1.0[a]	150	<1m	15.0[a]	1.0[a]	167	<1m	15.0[a]	1.0[a]	168	<1m
Mean:	**15.8**	**0.9919**	**190**	**4m**	**17.3**	**0.9153**	**167**	**<1m**	**16.6**	**0.8878**	**163**	**4m**	**17.5**	**0.9875**	**183**	**2m**	**17.1**	**0.9890**	**183**	**<1m**
Using All Points:	**13.9**	**0.8819**	**189**	**2m**	**14.5**	**0.7898**	**165**	**<1m**	**14.2**	**0.7764**	**161**	**1m**	**14.8**	**0.8136**	**181**	**<1m**	**14.5**	**0.8368**	**181**	**<1m**

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

Note: All data calculated between 20 and 20,000 Hz. m = meters.

6.2 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 size of the pile diameter, the type of sound attenuation employed, 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. 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 the computed distances to Level B thresholds that are presented in this section extend well beyond the measurements range of about 2.3 to 2.7 km. In some cases, these distances extend well beyond the range where land would 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 very far-field data points (i.e., beyond 300 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 very far-field data only was not used because distance to this threshold was generally closer than the very far field points.

6.3 Twenty-four-inch Vibratory Pile Driving Propagation and Threshold Distances, with Bubble Casing

6.3.1 Unweighted Transmission Loss and Distances to the Level B Threshold

Two types of 24-inch piles were installed during 2020 with the bubble casing: temporary trestle piles and template piles. The temporary trestle piles (S-1, S-3, and S-4) were driven for 4.5 to 11.8 minutes using an APE 300-6 vibratory hammer, while the template piles (T-13, T-14, T-15, and T-16) were driven much longer, at 19.2 to 25.6 minutes, using the smaller APE 200-6 vibratory hammer. Supplementing with the drift data, where available, 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 distances to the Level B threshold of 122.2 dB for the individual temporary trestle piles. Table 6-4 summarizes this information for all template piles. Figure 6-2 and 6-3 show the trestle and template piles, respectively, with the trendlines for each individual pile.

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

The unweighted frequency spectra for the close-in locations, the mooring locations, and the drift locations, which are shown in **Chapter 5**, were filtered using the marine mammal weighting curves shown on Figure 3-1. The overall weighted levels for each marine mammal weighting category (low frequency, mid-frequency, high frequency, Otariidae, and Phocidae) were then calculated by summing the 1/3-octave bands from 20 to 20,000 Hz. For each monitoring location (except SFD), the overall levels were plotted versus distance from the pile, and a transmission loss coefficient, R^2 value, and estimated level at 10 meters were determined. These data, including distances to the Level A threshold for each hearing group, are summarized in Table 6-3 for the 24-inch temporary trestle piles and Table 6-4 for the 24-inch template piles.

Table 6-3. Summary of unweighted transmission loss calculations for 24-inch temporary trestle piles installed with vibratory hammer and bubble casing

Pile ID	Date	Duration of Drive	Transmission Loss Coefficient	R^2 Value	Computed RMS Level at 10 meters	Distance to Level B Threshold (122.2 dB)
S-4 (Bent 3)	6/10/2020	11.2 minutes	15.3	0.990	165 dB	6.5 km
S-3 (Bent 3)	6/10/2020	11.8 minutes	13.6	0.980	160 dB	6.3 km
S-1 (Bent 3)	6/10/2020	4.5 minutes	14.7	0.990	166 dB	9.7 km
S-1 (Bent 2)	6/17/2020	10.8 minutes	17.7	0.980	168 dB	3.7 km
S-3 (Bent 1)	6/24/2020	7.8 minutes	13.9	--	159 dB	4.2 km
S-1 (Bent 1)	6/24/2020	9.6 minutes	14.4	0.998	158 dB	2.9 km
	Mean:	**9.3 minutes**	**14.9**	**0.988**	**162.5**	**5.5 km**
	Regression Using All Points:		**15.0**	**0.948**	**162.8**	**5.6 km**
	Using Far Field Points Only:		**15.5**	**0.738**	**163.7**	**5.4 km**

Table 6-4. Summary of unweighted transmission loss calculations for 24-inch template piles installed with vibratory hammer and bubble casing

Pile ID	Date	Duration of Drive	Transmission Loss Coefficient	R^2 Value	Computed RMS Level at 10 meters	Distance to Level B Threshold (122.2 dB)
T-13	6/12/2020	19.2 minutes	13.1	0.994	156 dB	3.8 km
T-14	6/12/2020	21.3 minutes	12.5	0.995	157 dB	7.6 km
T-15	6/16/2020	25.6 minutes	16.6	0.980	161 dB	2.2 km
T-16	6/16/2020	24.0 minutes	15.6	0.988	161 dB	3.1 km
	Mean:	**22.5 minutes**	**14.5**	**0.990**	**158.9 dB**	**3.8 km**
	Regression Using All Points:		**14.1**	**0.972**	**158.5 dB**	**3.7 km**
	Using Far Field Points Only:		**17.5**	**0.900**	**165.7 dB**	**3.1 km**

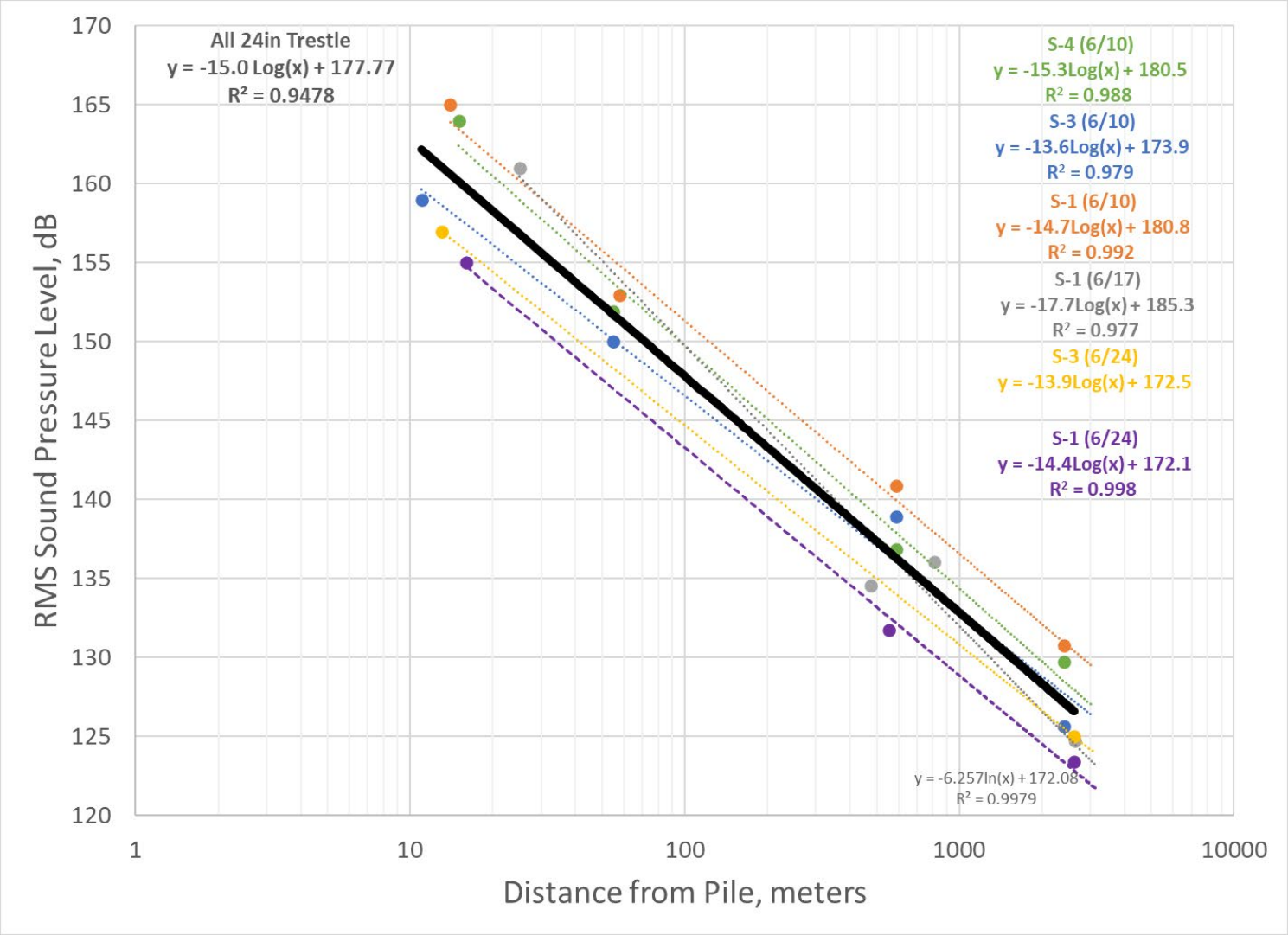


Figure 6-2. Data points and trendlines for all 24-inch temporary trestle piles installed with vibratory hammer and bubble casing

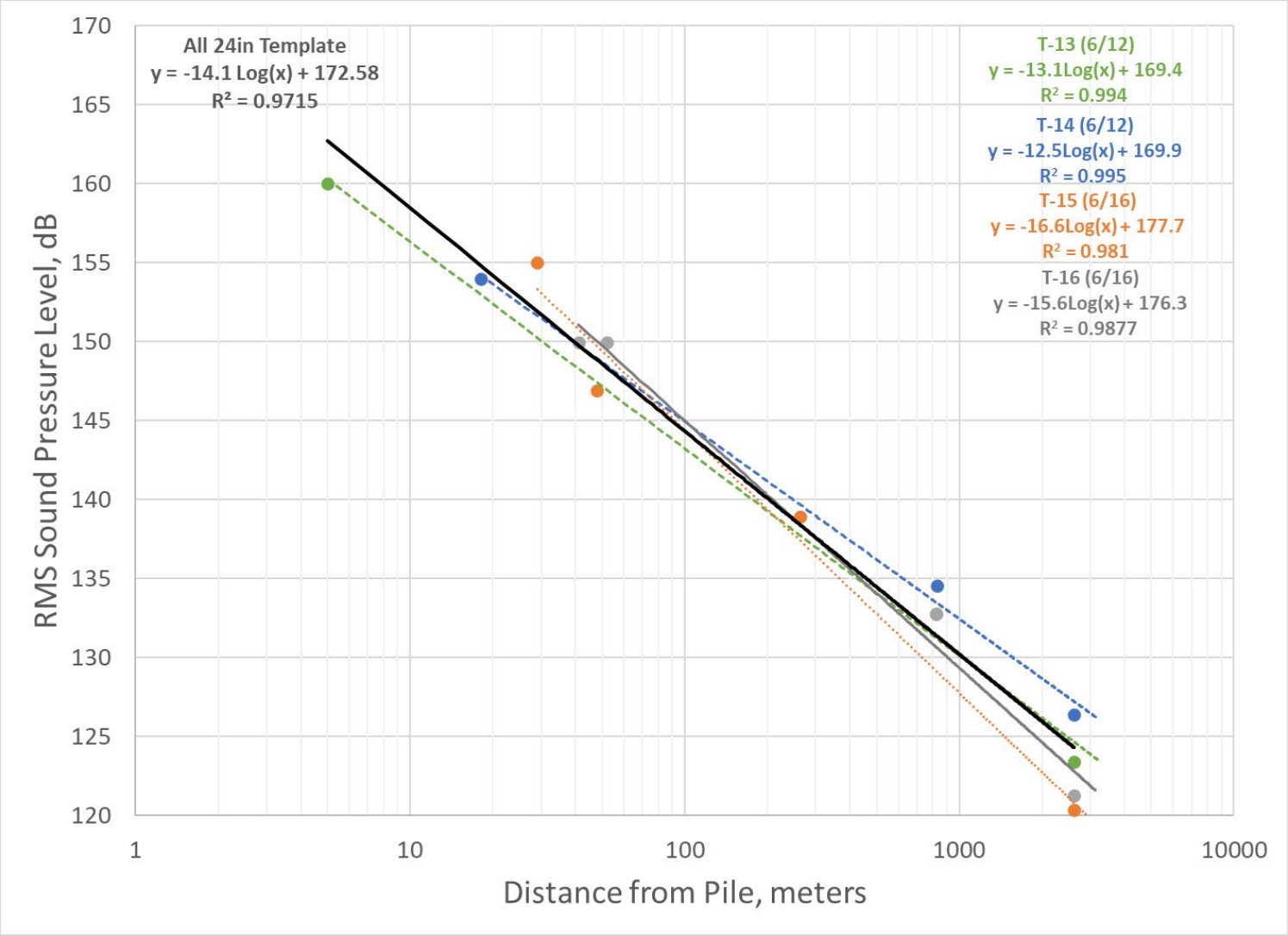


Figure 6-3. Data points and trendlines for all 24-inch template piles installed with vibratory hammer and bubble casing

Table 6-5. Summary of weighted transmission loss calculations for all 24-inch temporary trestle piles installed with vibratory hammer and bubble casing

	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
Pile ID	**T.L. Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 199 dB**	**T.L. Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 198 dB**	**T.L. Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 173 dB**	**T.L. Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 201 dB**	**T.L. Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 219 dB**
S-4 (Bent 3)	16.6	0.9939	190	3m	21.2	0.9807	171	<1m	20.8	0.9822	166	5m	19.6	0.9810	186	2m	19.0	0.9822	185	<1m
S-3 (Bent 3)	15.8	0.9987	188	2m	20.5	0.9913	171	<1m	20.4	0.9891	166	5m	18.5	0.9934	183	1m	18.1	0.9949	183	<1m
S-1 (Bent 3)	16.2	0.9977	188	2m	21.1	0.9946	173	<1m	21.5	0.9332	168	6m	18.2	0.9975	183	1m	18.0	0.9973	183	<1m
S-1 (Bent 2)	18.9	0.9934	194	6m	23.4	0.9895	181	2m	23.4	0.9948	177	15m	20.9	0.9955	192	4m	20.5	0.9963	191	<1m
S-3 (Bent 1)	14.0	1.0	180	<1m	18.1	1.0	162	<1m	17.2	1.0	158	1m	18.0	1.0	174	<1m	16.9	1.0	174	<1m
S-1 (Bent 1)	13.2	0.9429	183	<1m	16.1	0.7098	168	<1m	15.0	0.6599	164	3m	15.8	0.8681	178	<1m	15.2	0.8774	178	<1m
Mean:	**15.8**	**0.9878**	**187**	**2m**	**20.1**	**0.9443**	**171**	**<1m**	**19.7**	**0.9265**	**167**	**6m**	**18.5**	**0.9726**	**183**	**2m**	**18.0**	**0.9747**	**182**	**<1m**
Using All Points:	**15.8**	**0.9648**	**188**	**2m**	**19.7**	**0.9158**	**171**	**<1m**	**19.2**	**0.9028**	**167**	**5m**	**18.2**	**0.9296**	**183**	**1m**	**17.6**	**0.9404**	**182**	**<1m**

Note: All data calculated between 20 and 20,000 Hz.

Table 6-6. Summary of weighted transmission loss calculations for all 24-inch template piles installed with vibratory hammer and bubble casing

	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
Pile ID	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 199 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 198 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 173 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 201 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 219 dB**
T-13	12.5	0.9999	183	<1m	16.7	0.9962	164	<1m	16.6	0.9915	159	2m	14.0	0.9937	177	<1m	13.9	0.9964	177	<1m
T-14	13.0	0.9988	186	1m	17.8	0.9949	168	<1m	17.6	0.9895	163	3m	15.1	0.9967	182	<1m	14.9	0.9986	181	<1m
T-15	16.7	0.9452	189	3m	21.9	0.9835	177	1m	21.7	0.9852	174	11m	18.1	0.9483	186	2m	18.2	0.9511	186	<1m
T-16	15.5	0.9125	186	1m	19.0	0.9011	171	<1m	18.5	0.9145	166	4m	16.2	0.8517	181	<1m	16.3	0.8597	181	<1m
Mean:	**14.4**	**0.9641**	**186**	**1m**	**18.9**	**0.9689**	**170**	**<1m**	**18.6**	**0.9702**	**166**	**5m**	**15.9**	**0.9476**	**182**	**<1m**	**15.8**	**0.9515**	**181**	**<1m**
Using All Points:	**14.1**	**0.9322**	**186**	**1m**	**18.5**	**0.9404**	**170**	**<1m**	**18.7**	**0.9401**	**166**	**4m**	**15.5**	**0.9328**	**181**	**<1m**	**15.4**	**0.9214**	**181**	**<1m**

Note: All data calculated between 20 and 20,000 Hz.

6.4 Forty-eight-inch Vibratory Pile Driving Propagation and Threshold Distances, With Bubble Casing

6.4.1 Unweighted Transmission Loss and Distances to the Level B Threshold

Ten attenuated 48-inch piles were installed during 2020, with driving times ranging from 4 to 10 minutes. Additionally, one unattenuated 48-inch pile was also installed in 2020, with a drive time of 15 minutes. All 48-inch piles were driven using an APE 300-6 vibratory hammer. Using the drift data, where available, Table 6-7 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 122.2 dB for the individual attenuated piles. Table 6-8 provides the same information for the unattenuated pile. The data points and trendlines for each individual pile are shown on Figure 6-4 for the attenuated piles and on Figure 6-5 for the unattenuated pile. Note that computed distances to Level B thresholds were highly variable due to the low transmission loss computed for some piles. The low computed transmission loss is further examined in Section 6.9, where the effects of very low-frequency sounds that are inaudible to many hearing groups greatly affect sound transmission.

Table 6-7. Summary of unweighted transmission loss calculations for all 48-inch attenuated piles installed with vibratory hammer

Pile ID	Date	Duration of Drive	Transmission Loss Coefficient	R^2 Value	Computed RMS Level at 10 meters	Distance to Level B Threshold (122.2 dB)
A-1	6/10/2020	4.7 minutes	12.2	0.977	168.7	66.6 km
D-1	6/10/2020	5.0 minutes	8.8	0.897	165.2	*759.3 km*
E-1	6/12/2020	5.2 minutes	15.4	0.884	171.9	17.2 km
B-2	6/12/2020	4.0 minutes	15.2	0.867	167.0	9.0 km
HT-2	6/14/2020	9.2 minutes	13.1	0.903	163.7	14.7 km
C-2	6/14/2020	10.0 minutes	11.7	0.900	164.9	51.7 km
E-4	6/19/2020	10.1 minutes	13.3	0.984	161.7	9.5 km
GT-3	6/20/2020	7.7 minutes	15.2	0.999	175.8	32.8 km
B-5	6/23/2020	9.8 minutes	14.5	--	164.6	8.5 km
B-4	6/24/2020	8.0 minutes	12.7	--	158.9	7.6 km
Mean:		**7.4 minutes**	**13.2 (13.7 [a])**	**0.9342**	**166.2**	**107.7 km (24.2 km)[a]**
Regression Using All Points:			**13.0**	**0.830**	**166.2**	**23.7 km**
Using Far Field Points Only:			**19.2**	**0.5950**	**179.3**	**9.4 km**

[a] Without outlier value of 759.3 km.

Table 6-8. Summary of unweighted transmission loss calculations for the 48-inch unattenuated pile installed with vibratory hammer

Pile ID	Date	Duration of Drive	Transmission Loss Coefficient	R^2 Value	Computed RMS Level at 10 meters	Distance to Level B Threshold (122.2 dB)
B-1	6/16/2020	15 minutes	18.2	0.996	174	7.0 km

While the unattenuated pile exhibited a higher near-source level, the transmission loss coefficient was much greater (i.e., sound levels decreased at a greater rate with increased distance). This resulted in a computed Level B zone that was much smaller than computed for the attenuated conditions. In fact, the computed distance to the Level B zone was shorter than any of the distances computed for the attenuated conditions. This illustrates how sensitive the calculations of the Level B zone (which extends well beyond the measurement range) are to the computed transmission loss coefficient.

6.4.2 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 6-9 for the 48-inch attenuated piles and in Table 6-10 for the 48-inch unattenuated pile.

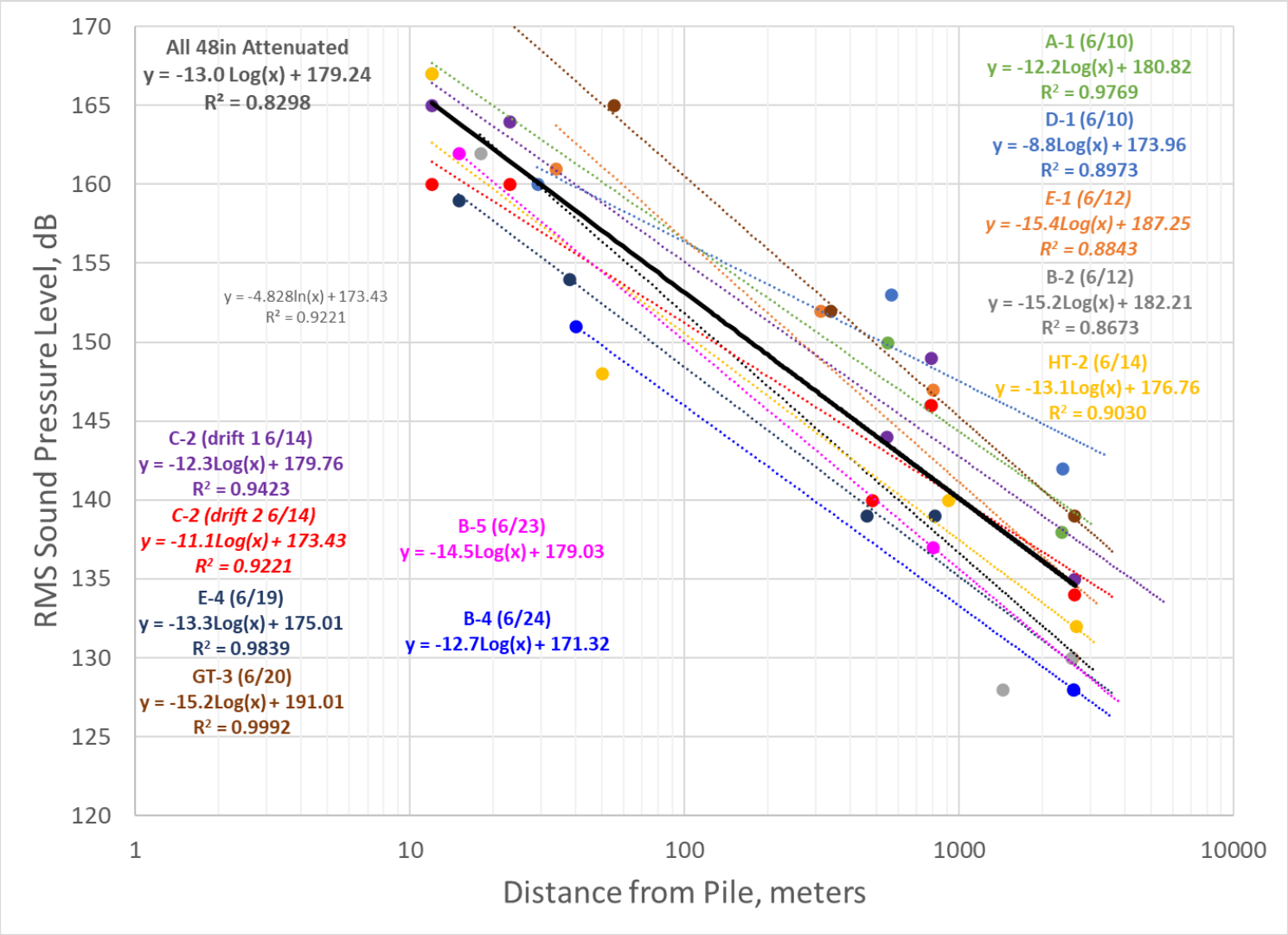


Figure 6-4. Data points and trendlines for all 48-inch attenuated piles installed with vibratory hammer

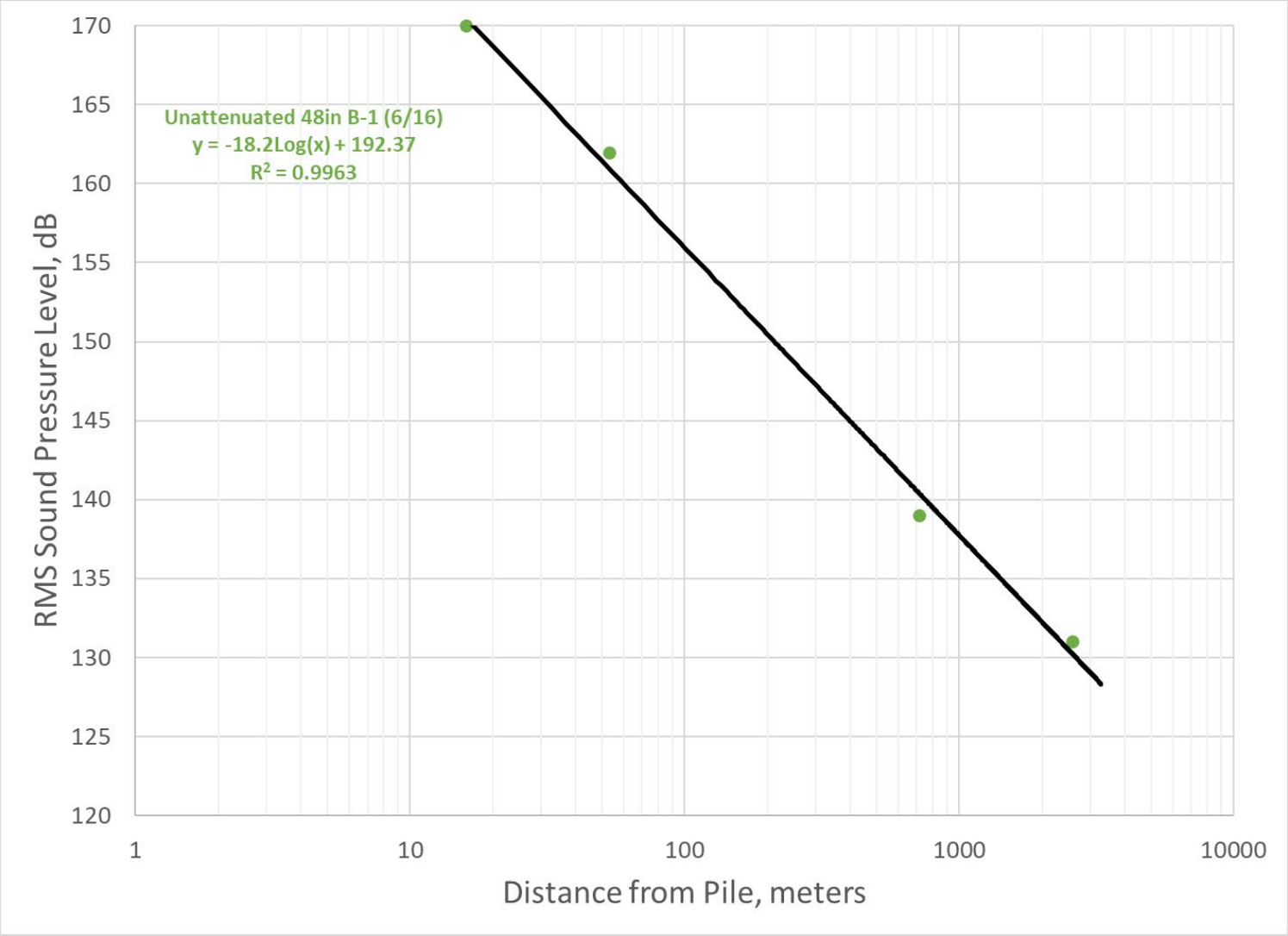


Figure 6-5. Data points and trendlines for the 48-inch unattenuated pile installed with vibratory hammer

Table 6-9. Summary of weighted transmission loss calculations for all 48-inch attenuated piles installed with vibratory hammer

	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
Pile ID	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 199 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 198 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 173 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 201 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 219 dB
A-1	11.4	0.9963	179	<1m	11.9	0.9605	144	<1m	11.8	0.9659	140	<1m	10.0	0.9295	161	<1m	10.2	0.9845	164	<1m
D-1	11.8	0.9857	180	<1m	17.0	0.9433	154	<1m	16.0	0.9235	149	<1m	16.1	0.9713	169	<1m	14.6	0.9981	170	<1m
E-1	14.5	0.9648	180	<1m	16.2	0.9048	153	<1m	15.3	0.8677	149	<1m	18.5	0.9987	167	<1m	16.5	0.9924	167	<1m
B-2	15.2	0.9595	178	<1m	11.3	0.6815	143	<1m	10.1	0.5831	137	<1m	14.2	0.9964	162	<1m	14.4	0.9995	164	<1m
HT-2	13.1	0.9685	174	<1m	6.8	0.4913	140	<1m	6.3	0.4313	137	<1m	11.8	0.9418	158	<1m	12.0	0.9501	160	<1m
C-2 (drift 1)	13.3	0.9210	183	<1m	15.2	0.7795	160	<1m	15.2	0.7946	157	<1m	14.2	0.7935	176	<1m	13.8	0.8158	175	<1m
C-2 (drift 2)	12.7	0.9108	180	<1m	14.2	0.7692	158	<1m	14.0	0.7781	154	<1m	14.1	0.7933	173	<1m	13.7	0.8097	173	<1m
E-4	14.0	0.9945	184	<1m	19.8	0.8540	169	<1m	19.6	0.8245	166	<1m	16.8	0.9753	178	<1m	16.4	0.9748	178	<1m
GT-3	15.4	0.9948	201	13m	24.6	0.9989	189	4m	26.1	0.9985	186	30m	18.4	0.9945	198	7m	18.0	0.9955	197	<1m
B-5	13.7	1.0	180	<1m	3.7	1.0	141	<1m	2.1	1.0	136	<1m	9.9	1.0	160	<1m	11.5	1.0	164	<1m
B-4	14.8	1.0	185	1m	18.4	1.0	166	<1m	17.0	1.0	160	2m	18.5	1.0	182	1m	17.7	1.0	181	<1m
Mean:	**13.6**	**0.9724**	**182**	**2m**	**14.5**	**0.8530**	**156**	**<1m**	**14.0**	**0.8334**	**152**	**4m**	**14.8**	**0.9449**	**171**	**<1m**	**14.4**	**0.9564**	**172**	**<1m**
Using All Points:	**14.0**	**0.7565**	**183**	**<1m**	**15.5**	**0.6157**	**158**	**<1m**	**15.2**	**0.6084**	**154**	**<1m**	**15.5**	**0.6439**	**173**	**<1m**	**15.1**	**0.6754**	**173**	**<1m**

Note: All data calculated between 20 and 20,000 Hz.

Table 6-10. Summary of weighted transmission loss calculations for the 48-inch unattenuated pile installed with vibratory hammer

	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
Pile ID	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 199 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 198 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 173 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 201 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 219 dB
B-1	19.6	0.9942	199	10m	24.7	0.9743	188	4m	25.6	0.9703	184	28m	21.1	0.9924	197	6m	21.1	0.9916	196	<1m

Note: All data calculated between 20 and 20,000 Hz.

6.5 Seventy-two-inch Air Bubble Casings Vibratory Pile Driving Propagation and Threshold Distances

6.5.1 Unweighted Transmission Loss and Distances to the Level B Threshold

Five 72-inch air bubble casings were installed during 2020, with driving times ranging from less than 1 minute to 8.3 minutes. All casings were driven using an ICE 44-B vibratory hammer. Table 6-11 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 the individual casings. Figure 6-6 shows the data points and trendlines for each casing.

Table 6-11. Summary of unweighted transmission loss calculations for all 72-inch air bubble casings

Pile ID	Date	Duration of Drive	Transmission Loss Coefficient	R^2 Value	Computed RMS Level at 10 meters	Distance to Level B Threshold (122.2 dB)
D-1 Casing	6/9/2020	8.3 minutes	16.6	--[a]	159	--[a]
C-2 Casing	6/14/2020	7.8 minutes	15.4	--[a]	156	--[a]
A-2 Casing	6/14/2020	3.9 minutes	--[a]	--[a]	--[a]	--[a]
D-5 Casing	6/20/2020	3.1 minutes	14.0	--[a]	154	--[a]
E-5 Casing	6/20/2020	0.6 minutes	13.7	--[a]	154	--[a]
Mean:		**4.7 minutes**	**14.9**	--[a]	**156**	--[a]
Regression Using All Points:			**14.8**	**0.930**	**154.8**	**1.5 km**
Using Far Field Points Only:			--[b]	--[b]	--[b]	--[b]

[a]Typically one or two measurements made per casing.

[b]Only two measurements in very far field.

6.5.2 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 6-12 for the 72-inch air bubble casings.

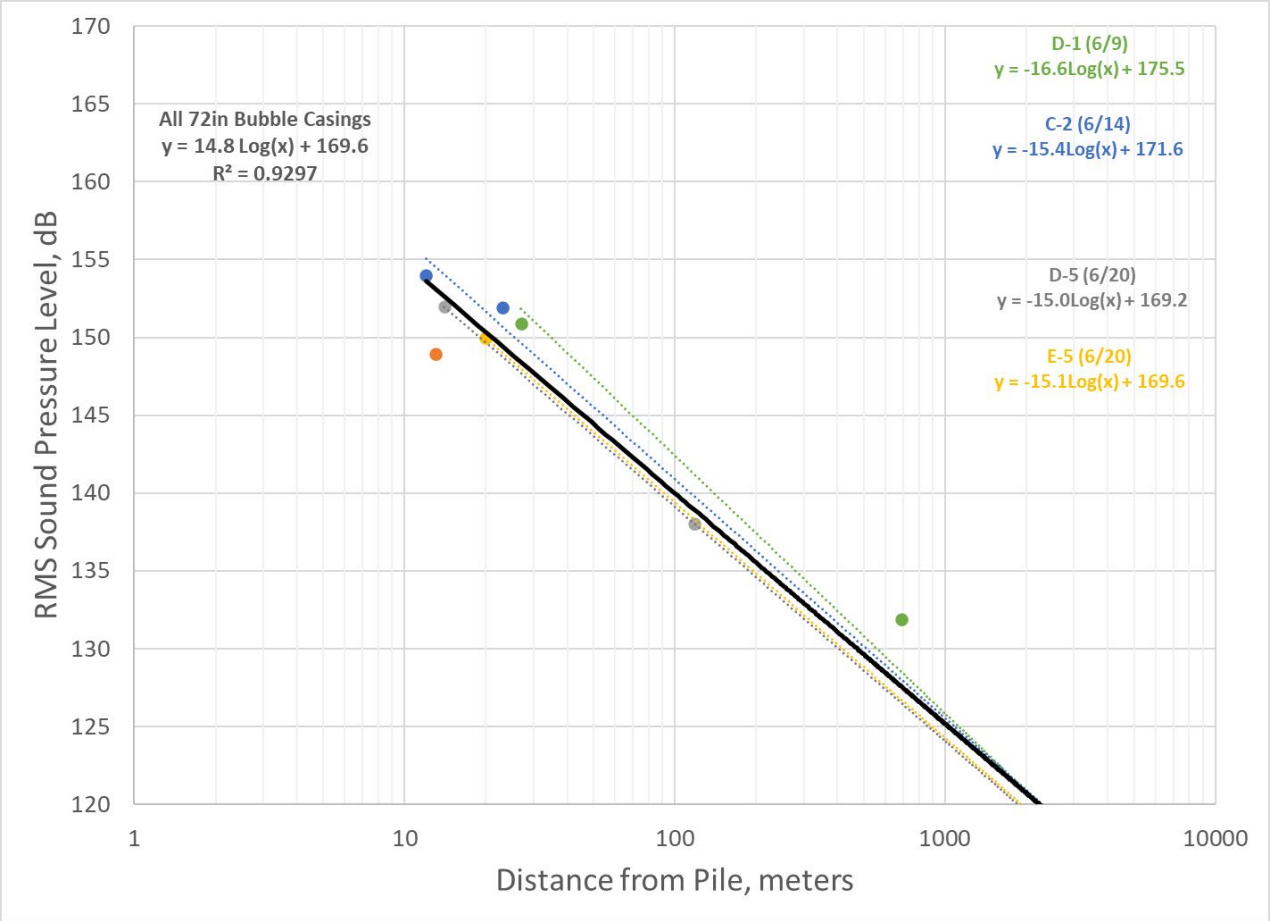


Figure 6-6. Data points and trendlines for 72-inch air bubble casings

Table 6-12. Summary of weighted transmission loss calculations for all 72-inch air bubble casings

	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
Pile ID	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 199 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 198 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 173 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 201 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 219 dB**
D-1 Casing	17.4	0.9969	184	1m	23.0	0.9980	170	<1m	22.6	0.9703	165	5m	20.2	0.9975	181	1m	19.9	0.9981	180	<1m
C-2 Casing	14.7	0.9935	180	<1m	17.3	0.9844	160	<1m	16.9	0.9801	157	1m	16.5	0.9950	173	<1m	16.1	0.9942	173	<1m
A-2 Casing	3.8	1.0	170	<1m	2.9	1.0	151	<1m	2.0	1.0	146	<1m	3.3	1.0	166	<1m	3.5	1.0	166	<1m
D-5 Casing	12.9	1.0	176	<1m	10.6	1.0	165	<1m	9.8	1.0	162	<1m	12.4	1.0	172	<1m	12.4	1.0	172	<1m
E-5 Casing	16.3	1.0	180	<1m	17.9	1.0	161	<1m	17.2	1.0	158	1m	19.1	1.0	174	<1m	18.5	1.0	174	<1m
Mean:	**15.3[a]**	**0.9976[a]**	**180[a]**	**<1m[a]**	**17.2[a]**	**0.9956[a]**	**164[a]**	**<1m[a]**	**16.6[a]**	**0.9876[a]**	**161[a]**	**2m[a]**	**17.1[a]**	**0.9981[a]**	**175[a]**	**<1m[a]**	**16.7[a]**	**0.9981[a]**	**175[a]**	**<1m[a]**
Using All Points:	**13.7**	**0.8929**	**178**	**<1m**	**17.0**	**0.8455**	**162**	**<1m**	**16.4**	**0.8165**	**158**	**1m**	**15.7**	**0.8666**	**174**	**<1m**	**15.4**	**0.8725**	**173**	**<1m**

[a]A-2 air bubble casing was not included in the mean calculation since the falloff rate is so shallow.

Note: All data calculated between 20 and 20,000 Hz.

6.6 Thirty-six-inch Pin Pile Vibratory Removal Propagation and Threshold Distances

6.6.1 Unweighted Transmission Loss and Distances to the Level B Threshold

Vibratory removal of one 36-inch pin pile without a bubble casing was monitored during 2020, lasting a total of 33.4 minutes. Table 6-13 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 the pin pile removal event. Figure 6-7 shows the data points and trendline for removal of this pin pile.

Table 6-13. Summary of unweighted transmission loss calculations for the 36-inch pin pile removal without a bubble casing

Pile ID	Date	Duration of Drive	Transmission Loss Coefficient	R^2 Value	Computed RMS Level at 10 meters	Distance to Level B Threshold (122.2 dB)
Pin Pile	6/24/2020	33.4 minutes	12.6	1.0	152	2.6 km

6.6.2 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 6-14 for the pin pile removal.

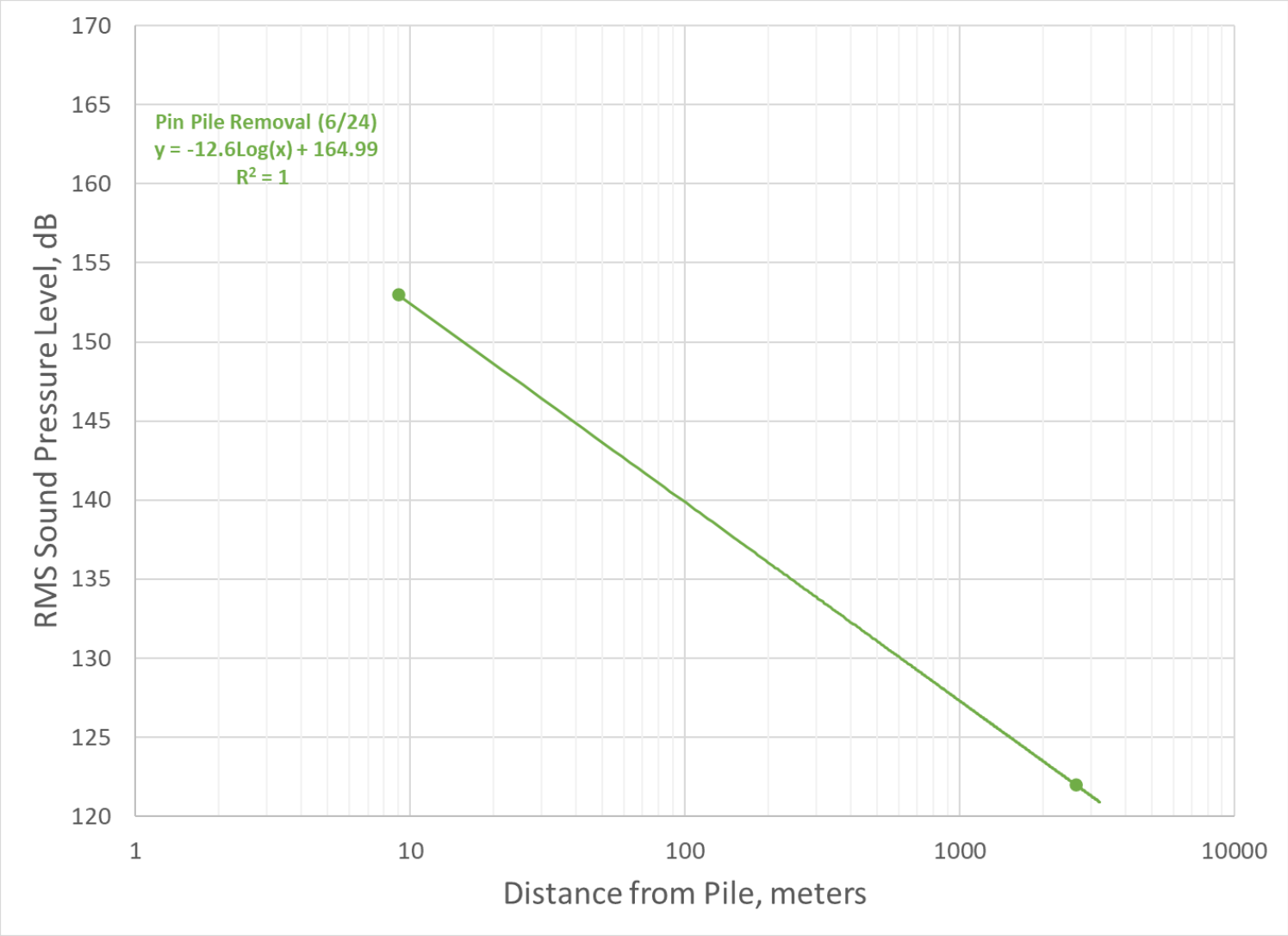


Figure 6-7. Data points and trendlines for the 36-inch pin pile removal without a bubble casing

Table 6-14. Summary of weighted transmission loss calculations for the 36-inch pin pile removal without a bubble casing

Pile ID	Low Frequency Cetaceans				Mid-Frequency Cetaceans				High Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
	T.L. Coef.	R^2 Value	Comp. Level at 10m	Dist. to 199 dB	T.L. Coef.	R^2 Value	Comp. Level at 10m	Dist. to 198 dB	T.L. Coef.	R^2 Value	Comp. Level at 10m	Dist. to 173 dB	T.L. Coef.	R^2 Value	Comp. Level at 10m	Dist. to 201 dB	T.L. Coef.	R^2 Value	Comp. Level at 10m	Dist. to 219 dB
Pin Pile	10.5	1.0	169	<1m	11.3	1.0	147	<1m	10.8	1.0	143	<1m	13.3	1.0	163	<1m	12.5	1.0	163	<1m

Note: All data calculated between 20 and 20,000 Hz.

6.7 Forty-eight-inch Impact Pile Driving Propagation and Threshold Distances

6.7.1 Unweighted Transmission Loss and Distances to the Thresholds

Ten attenuated 48-inch piles were installed during 2020, with driving times ranging from 4 to 10.1 minutes. Additionally, one unattenuated 48-inch pile was also installed in 2020, with a drive time of 15 minutes. All 48-inch piles were driven using a Delmag D-180 impact hammer. Using the drift data, where available, Table 6-15 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. Figure 6-8 shows the data points and trendlines for each individual pile impacted between June 10, 2020 and June 14, 2020. Figure 6-9 shows the same for all piles impacted between June 16, 2020, and June 24, 2020.

Table 6-15. Summary of unweighted transmission loss calculations for all 48-inch attenuated piles during impact driving - pulsed RMS SPLs

Pile ID	Date	Total No. of Strikes	Transmission Loss Coefficient	R^2 Value	Computed RMS Level at 10 meters	Distance to Level B Threshold (160 dB)
D-1	6/10/2020	950	8.8	0.8973	182	3.3 km
A-1 (drift 1)	6/10/2020	1,021	15.5	0.8735	191	1.1 km
A-1 (drift 2)			16.7	0.8693	192	0.8 km
E-1 (drift 1)	6/12/2020	1,101	11.8	0.9924	189	3.1 km
E-1 (drift 2)			9.5	0.8487	181	1.5 km
B-2	6/12/2020	231	11.1	0.9352	188	3.6 km
HT-2 (drift 1)	6/14/2020	990	10.4	0.9654	189	5.6 km
HT-2 (drift 2)			9.8	0.9384	189	9.7 km
C-2 (drift 1)	6/14/2020	936	10.0	0.9700	187	5.5 km
C-2 (drift 2)			10.5	0.9525	185	2.4 km
B-2	6/16/2020	757	11.3	0.9905	184	1.3 km
B-1	6/16/2020	969	10.6	0.9943	183	1.6 km
E-4 (drift 1)	6/19/2020	1,211	12.8	0.9525	193	3.8 km
E-4 (drift 2)			9.8	0.9404	189	8.9 km
GT-3 (drift 1)	6/20/2020	968	13.4	0.9877	196	4.7 km
GT-3 (drift 2)			14.8	0.9993	191	1.3 km
B-5	6/23/2020	1,394	12.7	0.9226	193	3.8 km
D-5 (drift 1)	6/24/2020	1,133	8.5	0.9567	182	4.1 km
D-5 (drift 2)			7.0	0.9983	177	2.4 km
A-1	6/24/2020	278	10.8	0.9079	182	1.1 km
	Mean:	**918**	**11.3**	**0.9471**	**187**	**3.5 km**
	Regression Using All Points:		**12.2**	**0.8050**	**189**	**2.3 km**
	Using Far Field Points Only:		**20.8**	**0.4533**	**208**	**2.0 km**

Additionally, Table 6-16 and Table 6-17 summarize the transmission loss coefficients, R^2 values, and estimated levels at 10 meters for peak and single-strike SELs, respectively. Figure 6-10 shows the peak trendlines of piles impacted between June 10, 2020, and June 14, 2020, while Figure 6-11 shows the peak trendlines for piles impacted between June 16, 2020, and June 24, 2020. Figure 6-12 and Figure 6-13 show the trendlines for single-strike SELs.

Table 6-16. Summary of unweighted transmission loss calculations for all 48-inch attenuated piles during impact driving – peak levels

Pile ID	Date	Total No. of Strikes	Transmission Loss Coefficient	R^2 Value	Computed Peak Level at 10 meters	Distance to Level A Threshold for HFC[a] (202 dB)
D-1	6/10/2020	950	12.2	0.9775	204	15
A-1 (drift 1)	6/10/2020	1,021	16.4	0.9381	204	13
A-1 (drift 2)			18.3	0.9450	209	24
E-1 (drift 1)	6/12/2020	1,101	14.4	0.9914	208	26
E-1 (drift 2)			10.0	0.9195	195	2
B-2	6/12/2020	231	13.2	0.9821	205	17
HT-2 (drift 1)	6/14/2020	990	12.3	0.9355	206	21
HT-2 (drift 2)			12.0	0.9299	207	26
C-2 (drift 1)	6/14/2020	936	10.8	0.9072	204	15
C-2 (drift 2)			12.6	0.9263	203	12
B-2	6/16/2020	757	12.5	0.9865	203	12
B-1	6/16/2020	969	11.8	0.9897	202	10
E-4 (drift 1)	6/19/2020	1,211	14.6	0.9946	210	35
E-4 (drift 2)			10.8	0.9007	204	15
GT-3 (drift 1)	6/20/2020	968	13.5	0.9976	210	39
GT-3 (drift 2)			14.6	1.0	209	30
B-5	6/23/2020	1,394	14.0	0.9889	210	37
D-5 (drift 1)	6/24/2020	1,133	9.4	0.7857	203	13
D-5 (drift 2)			11.0	0.998	198	4
A-1	6/24/2020	278	12.2	0.9584	201	8
	Mean:	**918**	**12.8**	**0.9513**	**205**	**19**
	Regression Using All Points:		**13.3**	**0.8856**	**205**	**17**
	Using Far Field Points Only:		**14.6**	**0.8099**	**208**	--

[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.

Table 6-17. Summary of unweighted transmission loss calculations for all 48-inch attenuated piles during impact driving – single-strike SEL values

Pile ID	Date	Total No. of Strikes	Transmission Loss Coefficient	R^2 Value	Computed Single-Strike Level at 10 meters
D-1	6/10/2020	950	9.5	0.9484	193
A-1 (drift 1)	6/10/2020	1,021	14.8	0.9247	179
A-1 (drift 2)			16.3	0.9199	169
E-1 (drift 1)	6/12/2020	1,101	11.0	0.9607	176
E-1 (drift 2)			10.6	0.8314	172
B-2	6/12/2020	231	11.4	0.9382	179
HT-2 (drift 1)	6/14/2020	990	10.1	0.9572	177
HT-2 (drift 2)			9.2	0.9219	177
C-2 (drift 1)	6/14/2020	936	8.9	0.9271	176
C-2 (drift 2)			9.1	0.9108	174
B-2	6/16/2020	757	12.0	0.9961	175
B-1	6/16/2020	969	10.8	0.9947	174
E-4 (drift 1)	6/19/2020	1,211	11.6	0.9724	180
E-4 (drift 2)			9.4	0.896	177
GT-3 (drift 1)	6/20/2020	968	12.9	0.9998	184
GT-3 (drift 2)			13.4	0.9996	178
B-5	6/23/2020	1,394	11.6	0.9758	181
D-5 (drift 1)	6/24/2020	1,133	9.7	0.9969	174
D-5 (drift 2)			8.9	0.9834	170
A-1	6/24/2020	278	10.8	0.9934	171
	Mean:	**918**	**11.1**	**0.9526**	**177**
	Regression Using All Points:		**11.6**	**0.8612**	**177**
	Using Far Field Points Only:		**12.8**	**0.7669**	**179**

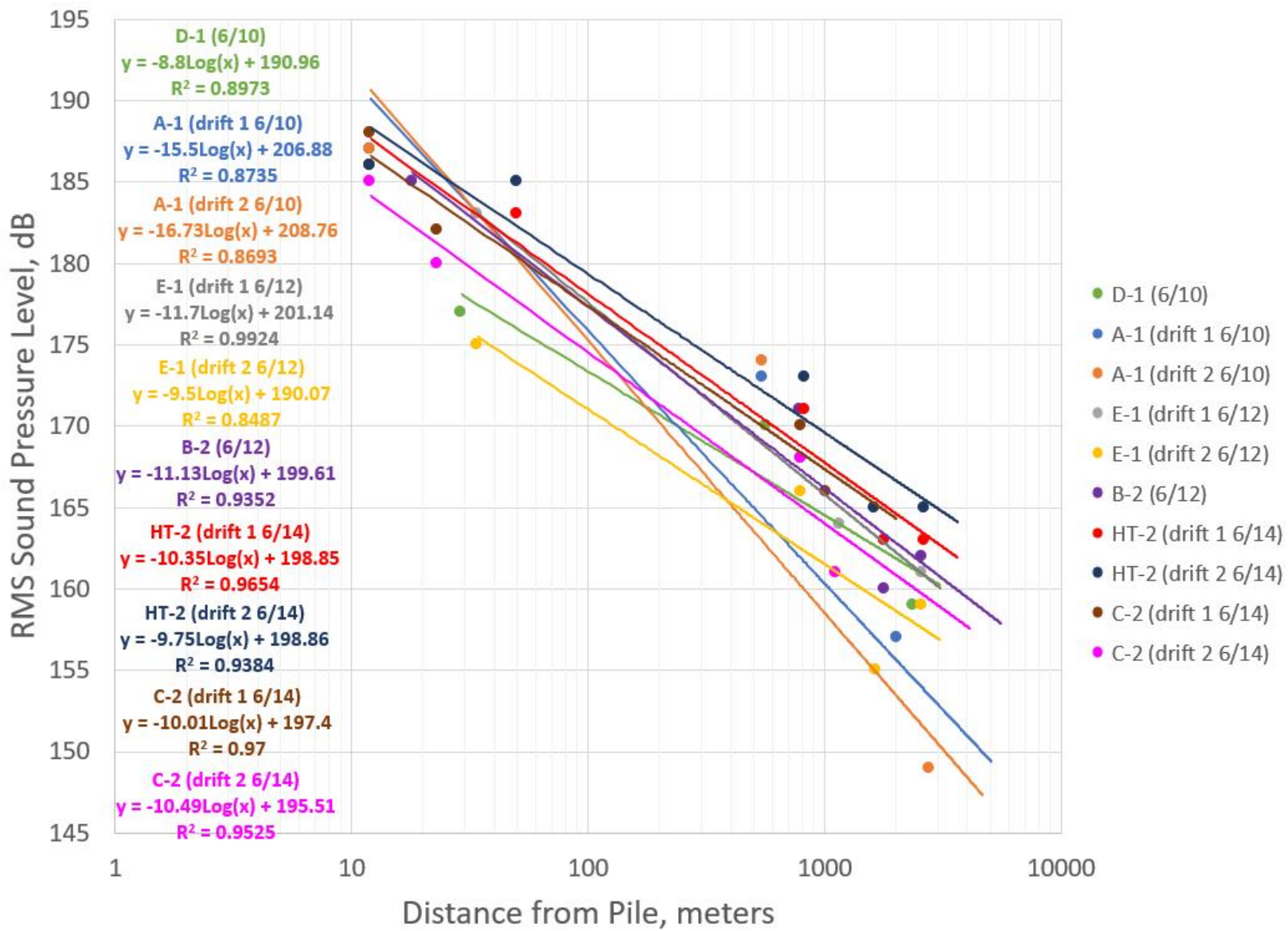


Figure 6-8. Data points and trendlines for 48-inch attenuated permanent piles during impact driving from June 10, 2020, through June 14, 2020

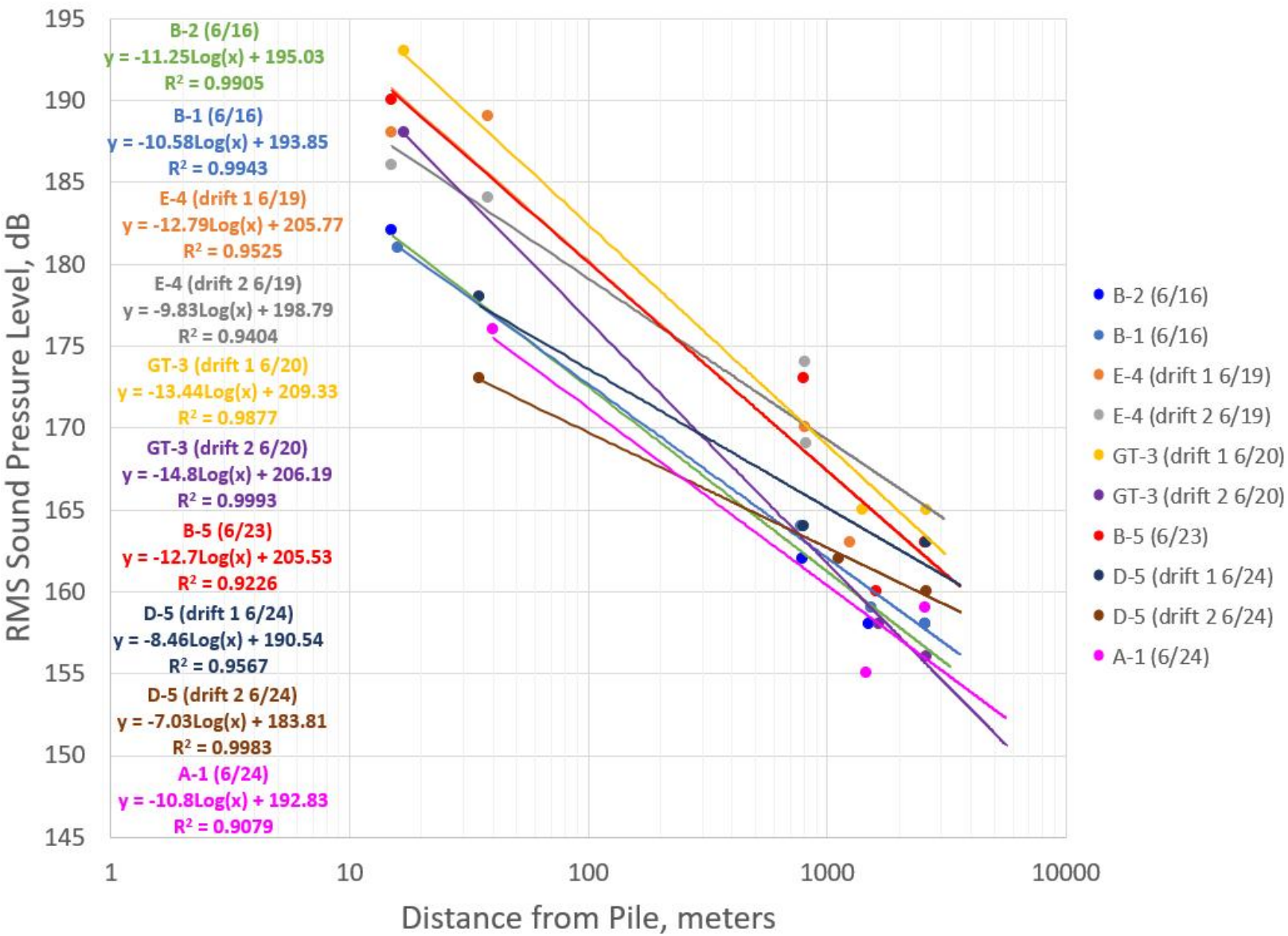


Figure 6-9. Data points and trendlines for 48-inch attenuated permanent piles during impact driving from June 16, 2020, through June 24, 2020

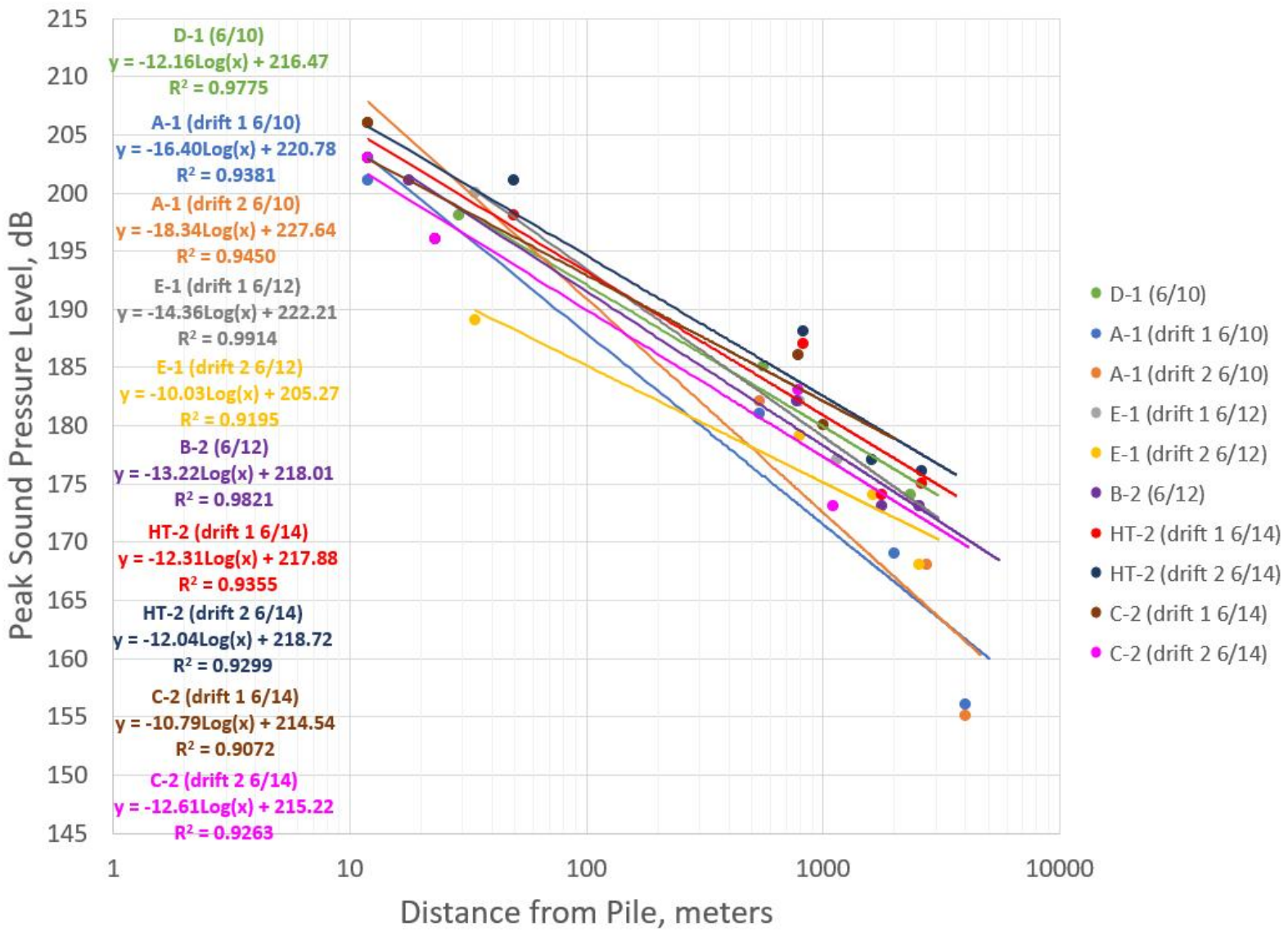


Figure 6-10. Peak level data points and trendlines for the 48-inch attenuated permanent piles during impact driving from June 10, 2020, through June 14, 2020

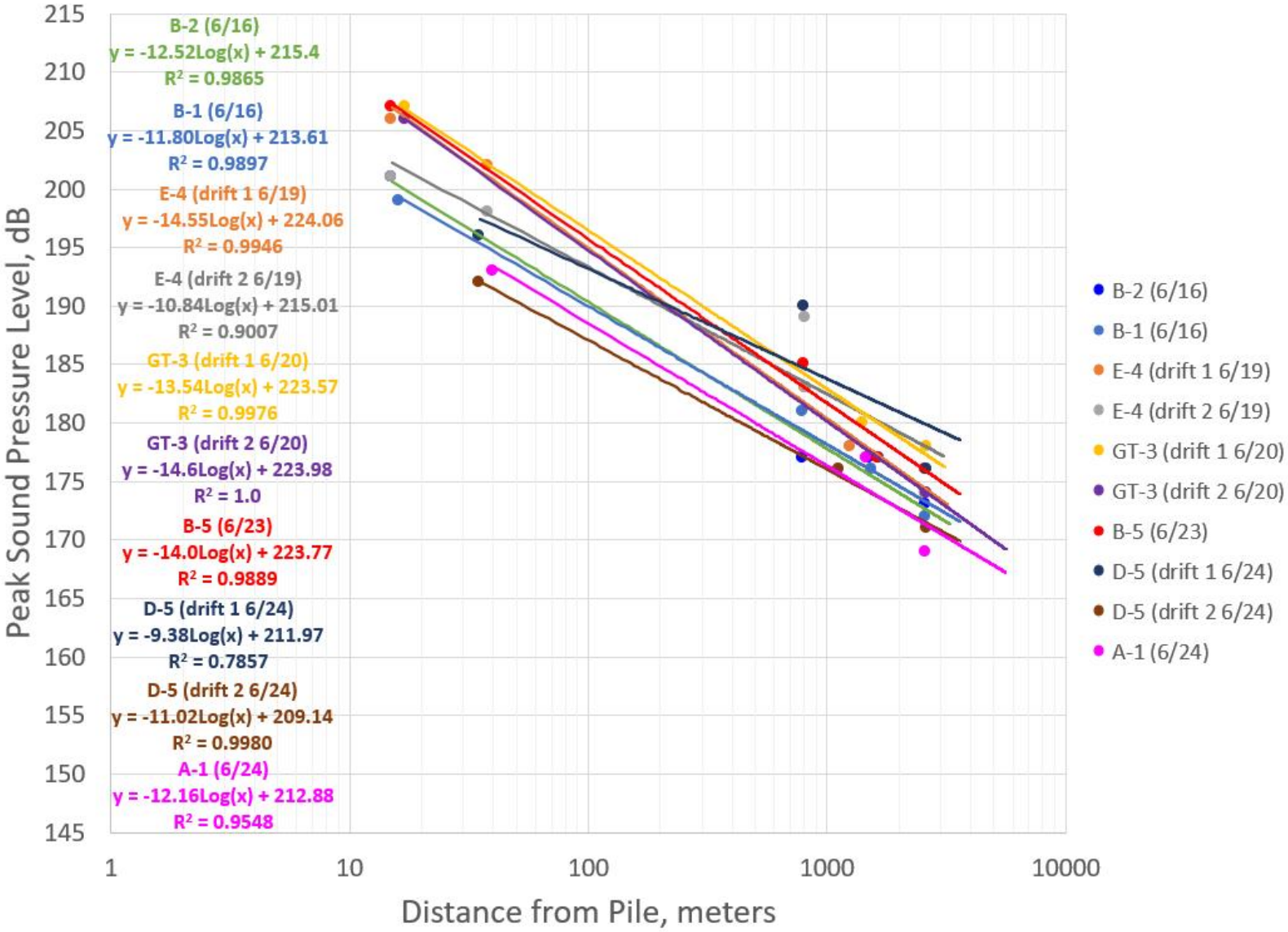


Figure 6-11. Peak level data points and trendlines for 48-inch attenuated permanent piles during impact driving from June 16, 2020, through June 24, 2020

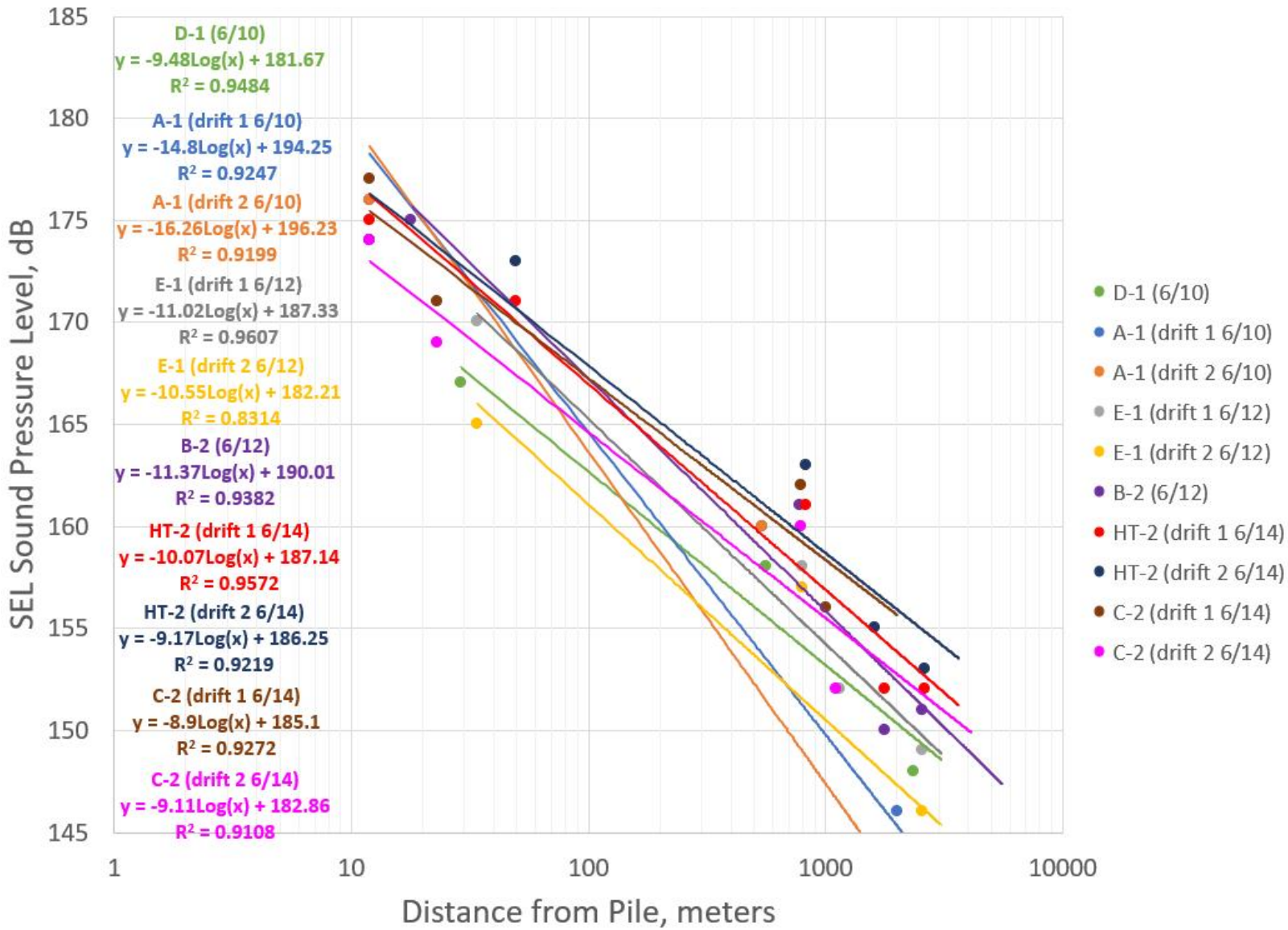


Figure 6-12. Single-strike SEL data points and trendlines for 48-inch attenuated permanent piles during impact driving from June 10, 2020, through June 14, 2020

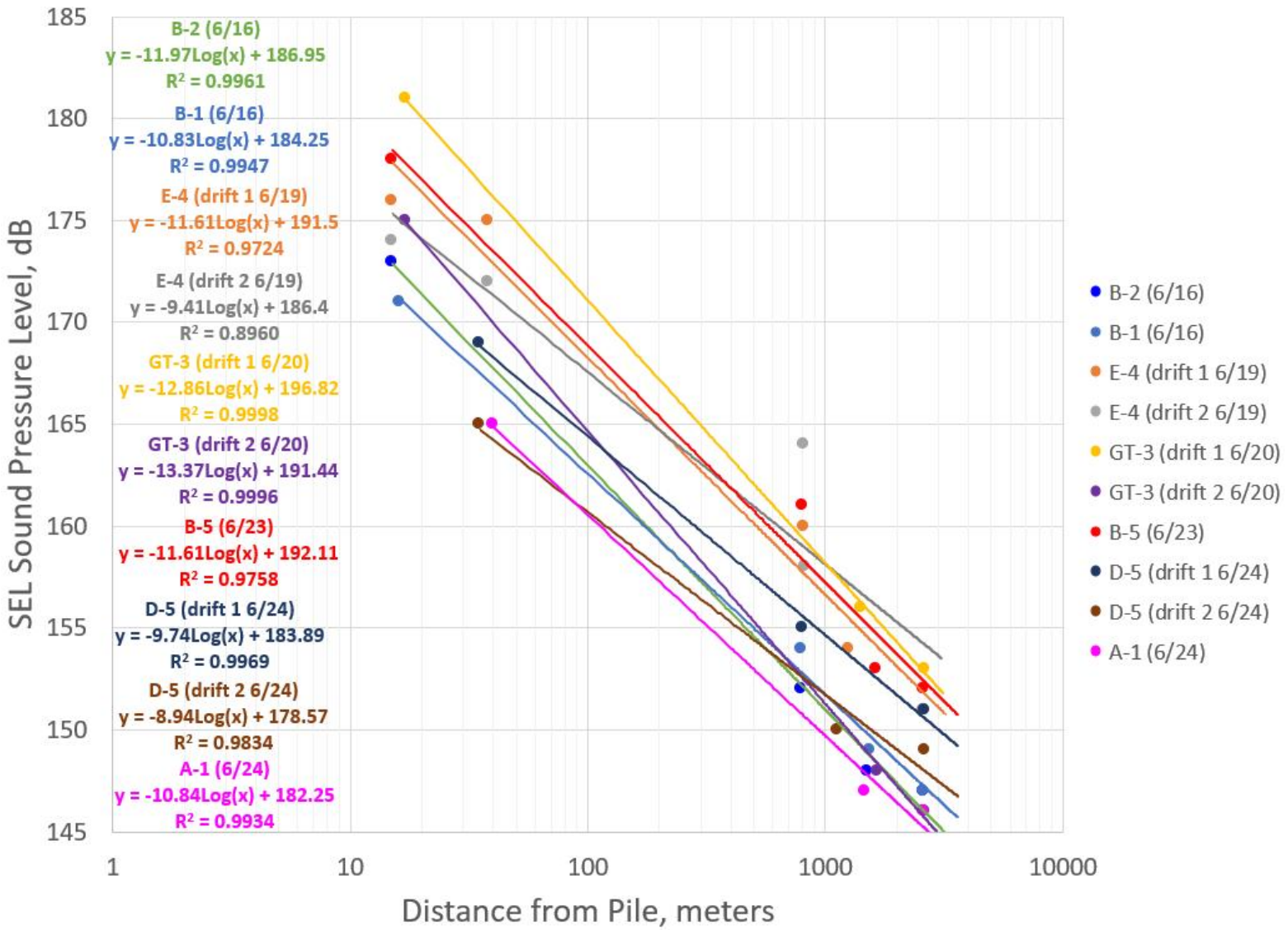


Figure 6-13. Single-strike SEL data points and trendlines for 48-inch attenuated permanent piles during impact driving from June 16, 2020, through June 24, 2020

6.7.2 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 6-18 for the 48-inch attenuated piles.

Table 6-18. Summary of weighted transmission loss calculations for all 48-inch attenuated piles during impact driving

	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
Pile ID	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 183 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 185 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 155 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 203 dB	TL Coef.	R^2 Value	Comp. Level at 10m	Dist. to 185 dB
D-1	10.4	0.9429	201	530m	18.3	0.9995	181	6m	20.1	0.9994	178	132m	13.5	0.9932	194	2m	12.7	0.9805	194	47m
A-1 (drift 1)	15.5	0.9065	200	118m	21.2	0.9587	177	4m	21.1	0.9564	173	71m	18.1	0.9291	192	2m	17.4	0.9255	192	24m
A-2 (drift 2)	17.2	0.9319	207	242m	21.4	0.9485	185	10m	21.0	0.9350	180	154m	19.6	0.9507	200	7m	19.1	0.9492	200	58m
E-1 (drift 1)	11.5	0.9634	202	56m	15.6	0.9795	172	2m	16.2	0.9429	167	54m	12.9	0.9581	190	1m	12.3	0.9630	191	30m
E-1 (drift 2)	10.9	0.8120	194	113m	17.7	0.9715	173	2m	17.8	0.9122	167	46m	5.2	0.8986	188	1m	13.7	0.8797	187	15m
B-2	11.8	0.9354	200	290m	18.5	0.9973	179	5m	19.5	0.9936	175	105m	14.6	0.9708	193	2m	13.9	0.9635	193	37m
HT-2 (drift 1)	10.6	0.9443	197	212m	16.1	0.8844	177	3m	17.3	0.8907	173	111m	12.7	0.8735	191	1m	12.2	0.8935	190	27m
HT-2 (drift 2)	9.9	0.9299	198	340m	15.6	0.8638	178	4m	17.0	0.8720	174	136m	11.9	0.8534	192	3m	11.5	0.8752	191	53m
C-2 (drift 1)	9.3	0.9052	197	341m	11.2	0.6781	172	<1m	11.0	0.6681	167	122m	6.0	0.8308	188	<1m	10.0	0.7809	189	26m
C-2 (drift 2)	10.1	0.9123	196	203m	12.6	0.7478	173	1m	12.1	0.7288	168	108m	7.3	0.9208	188	<1m	11.1	0.8383	189	22m
B-2	12.3	0.9988	201	316m	18.9	0.9912	181	6m	20.2	0.9641	178	129m	14.0	0.9991	193	2m	13.6	0.9995	193	37m
B-1	11.0	0.9970	201	440m	18.8	0.9933	183	7m	19.9	0.9706	179	160m	14.2	0.9970	195	3m	13.3	0.9978	194	48m
E-4 (drift 1)	12.1	0.9705	204	541m	17.5	0.9888	178	4m	18.8	0.9685	174	105m	14.4	0.9873	194	3m	13.6	0.9835	194	53m
E-4 (drift 2)	10.2	0.9086	201	513m	18.9	0.9767	179	6m	20.6	0.9742	176	101m	14.6	0.9613	194	3m	13.1	0.9499	193	43m
GT-3 (drift 1)	13.5	0.9993	209	878m	20.8	0.9978	192	21m	22.7	0.9951	188	292m	15.8	0.9990	204	11m	15.4	0.9998	203	149m
GT-3 (drift 2)	15.3	0.9983	203	201m	22.2	0.9989	186	11m	23.6	0.9896	182	145m	17.4	0.9990	197	5m	17.1	0.9987	197	49m

	Low-Frequency Cetaceans				Mid-Frequency Cetaceans				High-Frequency Cetaceans				Otariidae Pinnipeds				Phocidae Pinnipeds			
Pile ID	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 183 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 185 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 155 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 203 dB**	**TL Coef.**	**R^2 Value**	**Comp. Level at 10m**	**Dist. to 185 dB**
B-5	12.6	0.9744	204	476m	17.1	0.9996	178	4m	17.1	0.9932	171	87m	15.8	0.9935	198	5m	15.0	0.9901	197	67m
D-5 (drift 1)	9.5	0.9855	199	511m	14.1	0.9939	175	2m	15.2	0.9999	171	138m	11.2	0.9626	191	<1m	10.7	0.9709	191	53m
D-5 (drift 2)	9.1	0.9771	194	147m	14.4	0.9979	171	1m	15.5	0.9942	168	66m	11.0	0.9665	186	<1m	10.5	0.9696	186	12m
A-1	11.7	0.9916	191	46m	19.3	0.9831	167	1m	21.7	0.9780	164	25m	15.4	0.9845	183	<1m	13.8	0.9912	182	6m
Mean:	**11.7**	**0.9492**	**200**	**346m**	**17.5**	**0.9475**	**178**	**5m**	**18.4**	**0.9363**	**174**	**114m**	**13.8**	**0.9513**	**193**	**3m**	**13.5**	**0.9450**	**192**	**43m**
Using All Points:	**12.0**	**0.8417**	**200**	**279m**	**17.9**	**0.8793**	**178**	**4m**	**18.8**	**0.8771**	**174**	**101m**	**14.6**	**0.8517**	**193**	**2m**	**13.9**	**0.8580**	**193**	**36m**

Note: All data calculated between 20 and 20,000 Hz. See Table 6-17 for distances to peak thresholds.

6.8 Bubble Casing Performance

To measure air bubble casing performance, a pile would have to be driven unattenuated under circumstances similar to driving a pile with an attenuation system. Bubble casing testing was not conducted during this monitoring event. Except for the vibratory installation of 48-inch-diameter piles, air bubble casing performance could not be measured. One of the piles vibrated, Pile B-1, had to be vibrated unattenuated because it was suspected to have been obstructed. A pile guide was used that could not be accommodated by the air bubble casing. During a portion of the drive, the pile came in contact with the pile guide, possibly generating excessive noise for a short period of the driving. In any case, the performance of an air bubble casing during pile vibration is difficult to measure since the sound levels vary considerably over the driving of any single pile. To illustrate bubble casing performance, the 1/3-octave band spectra for selected 48-inch piles are compared against the spectra for the unattenuated pile, Pile B-1.

Figure 6-14 compares the spectra measured for unattenuated conditions (Pile B-1) at various distances against attenuated conditions for Pile A-1. Note that the sounds appear to be greatly attenuated for frequencies above about 500 Hz. However, sounds below 200 Hz appear unaffected by the air bubble casing. The fundamental frequencies are not only unaffected, but appear to attenuate at a low rate with increased distance. The effects of the air bubble casing in reducing overall sound levels at distant positions is not evident when summing all 1/3-octave band sound levels because levels at the 25 and 50 Hz bands dominate. Levels at these bands fall off with distance at a much lower rate than the higher frequency sounds, which contribute to the lower transmission losses computed for attenuated conditions.

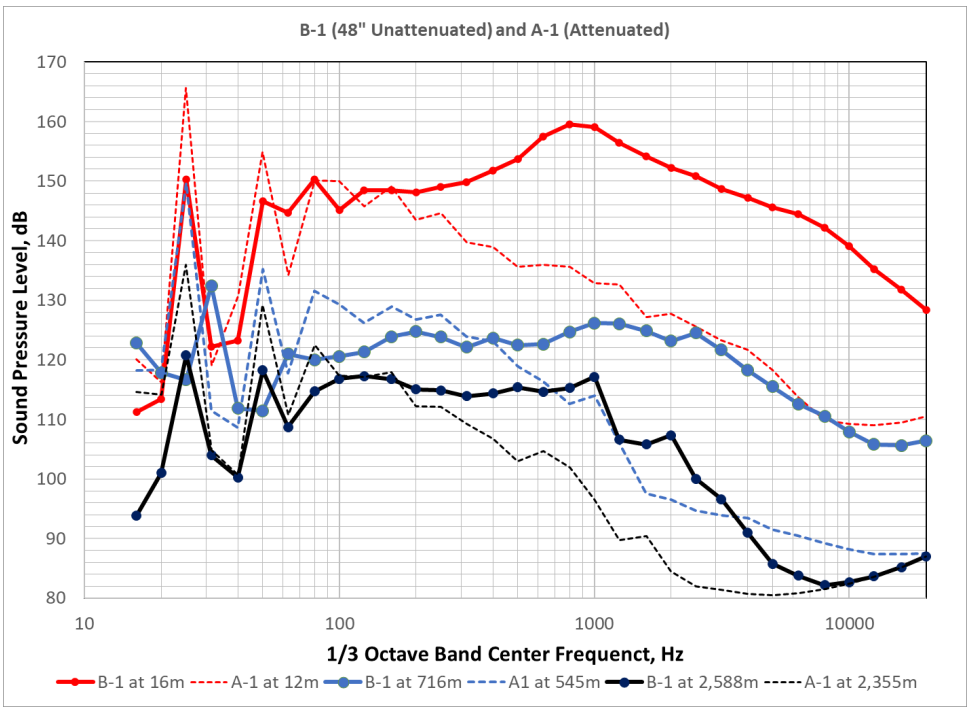


Figure 6-14. Comparison of Pile A-1 with unattenuated conditions (Pile B-1)

A second example is provided on Figure 6-15 for Pile HT-2, where the attenuated sounds are dominated by very low-frequency sounds.

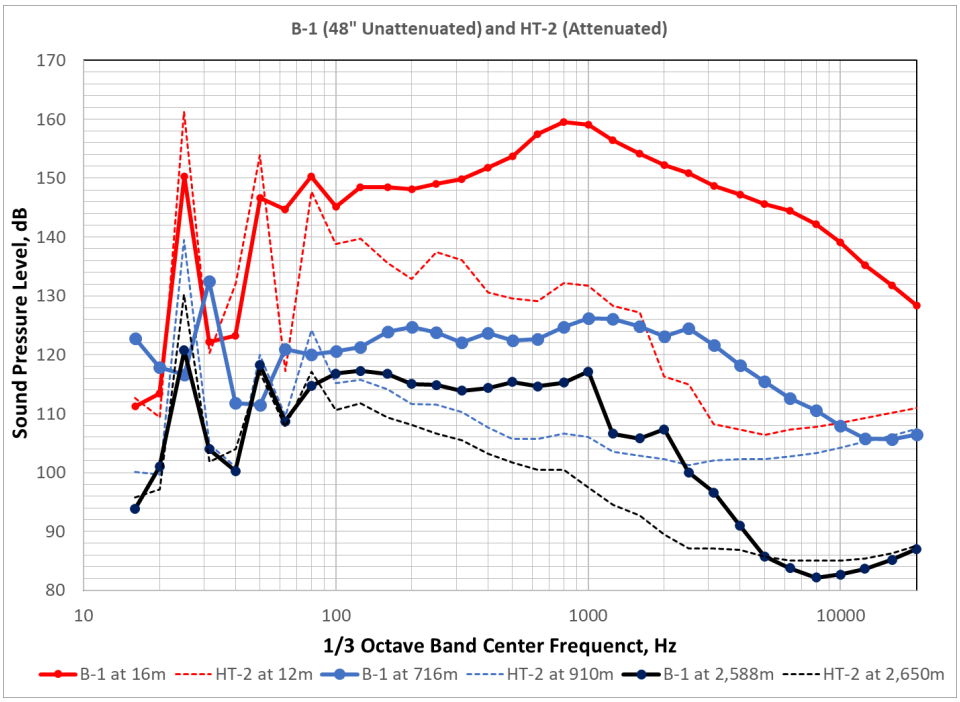


Figure 6-15. Comparison of Pile HT-2 with unattenuated conditions (Pile B-1)

An example of a case in which poor air bubble casing performance for installation of Pile GT-3 was suspected is shown on Figure 6-16. In this case, the frequency spectra are dominated by elevated sound levels across bands.

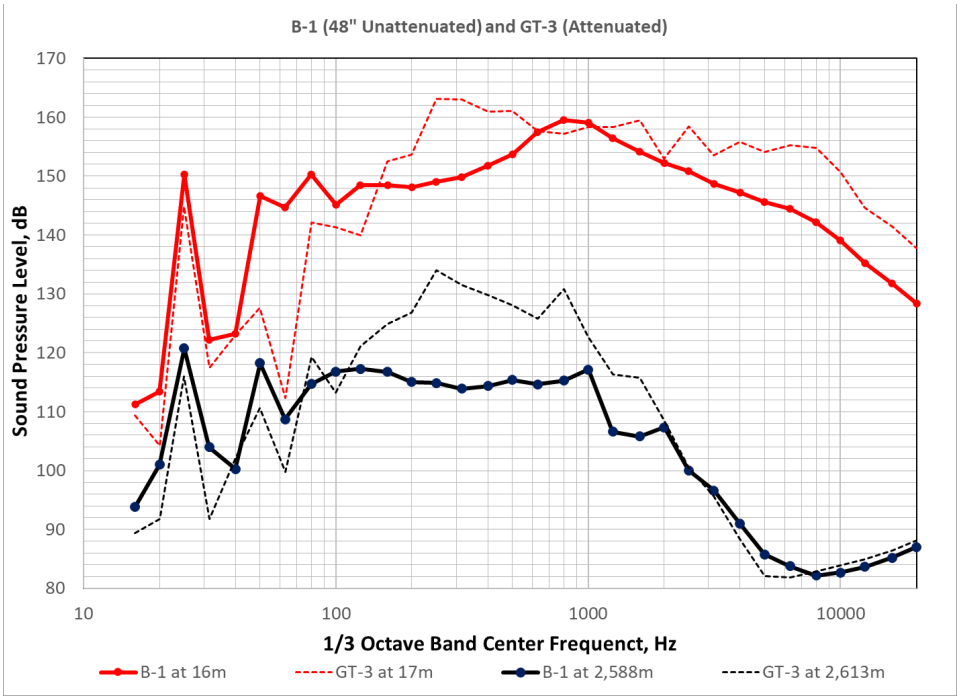


Figure 6-16. Comparison of Pile GT-3 with unattenuated conditions (Pile B-1)

One can compare overall measured levels for attenuated piles at 10 meters against unattenuated levels measured for the unattenuated pile (B-1) and those during the 2016 Test Pile Program (Austin et al. 2016; POA 2016, 2019). Table 6-19 compares unattenuated vibratory pile driving sound levels for 10 meters. Based on this comparison, the air bubble casing system may have reduced average near-source sound levels (i.e., at 10 meters) by 2 to 8 dB. However, the measured transmission loss was considerably lower than the unattenuated conditions measured for the Test Pile Program or unattenuated Pile B-1. Since an attenuation system would only lower sound levels, it appears that this study did not capture data that accurately depict the transmission loss for attenuated conditions over large distances. Note that the driving times for the 2020 project were much shorter.

Table 6-19. Comparison of attenuated and unattenuated 48-inch vibratory levels

Descriptor	2020 Attenuated Piles		2020 Unattenuated Pile B-1		2016 Test Pile Program Unattenuated Piles	
RMS continuous	166 dB	TL = 13.0	174 dB	TL = 18.2	168 dB	TL = 16.5
Duration	7 minutes average		15 minutes		25 minutes average	

There are no unattenuated conditions measured for 36-inch piles. However, examination of the 1/3-octave band spectra for each pile reveals indications of air bubble casing performance. Pile S2-2 appears to exhibit frequency spectra that indicate reductions of sound above 100 Hz, whereas the spectra for the other four piles do not show that feature. Similar to the 48-inch piles, the attenuated signature for the 36-inch piles is dominated by very low-frequency sounds at distant positions.

For 24-inch template and trestle piles, the bubble casing performance is more difficult to evaluate. Overall levels are lower than for the 36-inch and 48-inch piles; however, the 1/3-octave band frequency spectra indicate higher levels above 100 Hz where reductions due to bubble casing performance would be expected. Without unattenuated conditions for comparison, it is difficult to assess the performance of the air bubble casing system for these piles. It should be noted that the 25- and 50-Hz tones for the 24-inch piles are substantial, but not dominant, as was the case for the 48-inch piles.

For impact driving, there were also no unattenuated conditions to measure. However, one can compare overall measured levels for 10 meters against unattenuated levels measured during the 2016 Test Pile Program (Austin et al. 2016; POA 2016, 2019). Table 6-20 compares unattenuated impact pile driving sound levels for 10 meters. Based on this comparison, the air bubble casing reduced near-source sound levels (i.e., at 10 meters) by 9 dB peak, 11 dB RMS, and 10 dB single-strike SEL. Sound levels in the very far field do not appear to be reduced, resulting in a decreased transmission loss rate, when compared to unattenuated Test Pile Program conditions.

Table 6-20. Comparison of 2020 measured 48-inch impact levels to 2016 TPP – impact driving

Descriptor	2020 Measured Level Attenuated		2016 Test Pile Program Unattenuated	
Peak	205 dB	TL =13.3	214 dB	TL = 19.16
RMS pulse	189 dB	TL = 12.2	200 dB	TL = 18.35
SEL single strike	177 dB	TL = 11.6	187 dB	TL =16.85
Number of Strikes:	918 average		1,683 average	

6.9 Effects of Levels in the Very Low-Frequency Range of 20 to 50 Hz for Vibratory Sounds

Installation of several piles resulted in excessively high sound content in the very low-frequency range (below 50 Hz), which could not be attenuated by an air bubble casing. In some cases, these sounds appear to be amplified in the presence of the air bubble casing. Typical spectra for 24- and 36-inch piles showed peaks at 20 and 40 Hz frequency bands, respectively. The 36-inch pile, S-5 (Bent 1), and 24-inch pile, S-1, have peaks at 31.5 Hz, while S-5 (Bent 2) has a peak at 16 Hz. Twenty-four-inch piles T-15 and T-16 also have peaks at 25 Hz that are unrelated to vibratory driving. The 48-inch piles have peaks at 25, 50, and 80 Hz, with the 25-Hz peak dominating the overall sound level in most cases. Piles E-4 and B-4 have additional low-frequency peaks at 63 and 40 Hz, respectively, which are atypical. The 1/3-octave band spectra for Pile A-1 (a 48-inch attenuated pile) illustrate this effect, as shown on Figure 6-17. This effect is important to consider since these sounds are below the generalized hearing range for all but low-frequency cetaceans (NMFS 2018). Note that the overall sound levels reported are over the range of 20 to 20,000 Hz; therefore, these very low-frequency sounds are included in those levels.

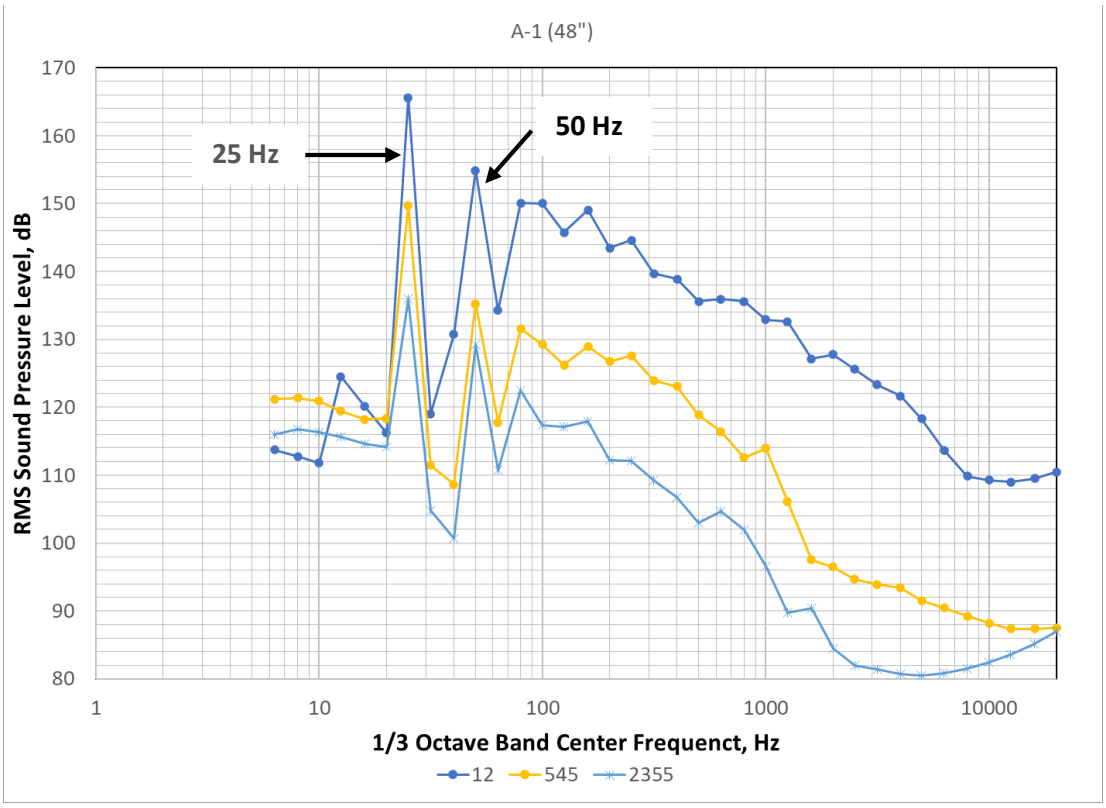


Figure 6-17. One-third-octave band spectra dominated by sounds at 25 and 50 Hz (A-1 24-inch)

To assess how much influence these high low-frequency bands contribute to the overall RMS level, the levels at frequency bands below 50 Hz were filtered out of the overall sound level calculation. This was accomplished by summing only the overall median levels for 1/3-octave bands of 50 to 20,000 Hz (rather than 20 to 20,000 Hz). The results are summarized in Table 6-21.

Filtering out levels at frequency bands below 50 Hz results in overall RMS levels that are up to 3 dB lower for 24- and 36-inch piles at every position. This effect was much greater for 48-inch piles, where overall RMS levels were up to 15 dB lower for certain piles. The largest effects were for Piles A-1, D-1, E-1, B-2, and HT-2, where the air bubble casing appeared to perform well. The average reduction by filtering the sounds for these piles were 7.7 dB (A-1), 10.3 dB (D-1), 7 dB (E-1), 4 dB (B-2), and 5.3 dB (HT-2) for all positions. The presence of these very low-frequency sounds substantially reduces the transmission loss coefficient and computed level at 10 meters, resulting in smaller estimated distances to the Level B thresholds for these piles. Note that the effect for unattenuated Pile B-1 and the pile with suspected poor air bubble casing performance, Pile GT-3, was negligible.

Table 6-21. Summary of RMS levels recalculated between 50 and 20,000 Hz for all 24-, 36-, and 48-inch piles

Pile Size	Pile ID	Distance from Pile (meters)	Median RMS Level for 20 to 20,000 Hz (dB)	Median RMS Level for 50 to 20,000 Hz (dB)	Level Reduction (dB)
24-inch	S-4	15	164	161	3
		55	152	152	0
		590	137	135	2
		2,400	130	128	2
	S-3	11	159	159	0
		55	150	150	0
		590	139	136	3
		2,400	126	124	2
	S-1	14	165	164	1
		58	153	153	0
		590	141	139	2
		2,400	131	130	1
	T-13	5	160	158	2
		824	133	131	2
		2,608	124	124	0
	T-14	18	154	153	1
		827	135	134	1
		2,606	127	127	0
	T-15	29	155	155	0
		48	147	144	3
		2,620	122	121	1
	T-16	41	150	150	0
		52	150	148	2
		823	133	130	3
		2,618	122	122	0
	S-1	25	161	160	1
		807	136	133	3
		2,623	126	125	1
	S-3	13	157	156	1
		2,620	125	124	1
	S-1	16	155	154	1
		2,620	124	124	0
	Range of Level Reduction for 24-inch Piles:				**0 to 3 dB**
	Average Level Reduction for 24-inch Piles:				**1.2 dB**

Pile Size	Pile ID	Distance from Pile (meters)	Median RMS Level for 20 to 20,000 Hz (dB)	Median RMS Level for 50 to 20,000 Hz (dB)	Level Reduction (dB)
36-inch	S-5 (Bent 3)	55	154	154	0
		690	142	141	1
		2,335	130	130	0
	S-5 (Bent 2)	31	157	157	0
		44	149	149	0
		815	133	130	3
		2,616	127	126	1
	S-2 (Bent 2)	25	161	161	0
		807	136	133	3
		2,623	128	125	3
	S-5 (Bent 1)	14	156	156	0
		2,615	124	123	1
	S-2 (Bent 1)	10	159	156	3
	Range of Level Reduction for 36-inch Piles:				**0 to 3 dB**
	Average Level Reduction for 36-inch Piles:				**1.2 dB**
48-inch	A-1	12	167	160	7
		545	150	141	9
		2,355	138	131	7
	D-1	29	160	155	5
		565	153	138	15
		2,370	142	131	11
	E-1	34	155	147	8
		798	146	134	12
		2,584	126	125	1
	B-2	18	162	159	3
		781	147	139	8
		2,568	129	128	1
	HT-2	12	163	157	6
		50	147	143	4
		2,650	131	125	6
	C-2	12	161	160	1
		23	160	158	2
		789	149	144	5
		2,611	133	131	2
	B-1 (unattenuated)	16	167	167	0
		53	159	159	0
		2,588	130	129	1
	E-4	15	159	159	0
		38	151	150	1
		810	138	137	1
		2,595	129	128	1

Pile Size	Pile ID	Distance from Pile (meters)	Median RMS Level for 20 to 20,000 Hz (dB)	Median RMS Level for 50 to 20,000 Hz (dB)	Level Reduction (dB)
	GT-3	17	172	172	0
		55	165	165	0
		2,616	139	139	0
	B-5	15	162	158	3
		800	137	134	3
	B-4	40	151	151	0
		2,605	128	126	2
	Range of Reduction for 48-inch Piles:				**0 to 15 dB**
					3.8 dB

6.10 Effects of Tidal Conditions

Water depths varied by pile and tidal conditions. Tidal conditions caused water depths to vary by up to 10 meters for the extreme conditions that were encountered. Based on tidal conditions provided for each day of monitoring, all vibratory piles were grouped by low-, mid-, and high-tide conditions. Table 6-22 summarizes the transmission loss coefficients and estimated RMS levels at 10 meters for different groupings. On average, the transmission loss coefficients under high-tide conditions (deeper water) resulted in lower falloff rates (average of 12.7) than the low- and mid-tide conditions. However, tide (or water depth) is only one effect on the transmission of sound over distance. The type of sound and effectiveness of attenuations systems may have greater effects.

Table 6-22. Effects of tidal conditions

Tidal Conditions	Pile Size	Date	Pile ID	Estimated RMS Level at 10 meters	Transmission Loss Coefficient
Low Tide	24-inch trestle	6/24/2020	S-1 (Bent 1)	158	14.2
	24-in template	6/12/2020	T-13	156	12.9
		6/12/2020	T-14	157	12.2
		6/16/2020	T-16	160	15.3
	36-in trestle	6/9/2020	S-5 (Bent 3)	166	14.8
		6/17/2020	S-2 (Bent 2)	167	16.3
		6/24/2020	S-5 (Bent 1)	158	14.1
	48-in permanent (attenuated)	6/19/2020	E-4	162	13.3
		6/20/2020	GT-3	176	15.2
		6/24/2020	B-4	159	12.7
			Range of values:	**156 to 176**	**12.2 to 16.3**
			Average:	**162**	**14.1**
Mid Tide	24-inch trestle	6/10/2020	S-4 (Bent 3)	165	15.2
		6/17/2020	S-1 (Bent 2)	167	17.1
		6/24/2020	S-3 (Bent 1)	159	13.9
	24-in template	6/16/2020	T-15	160	15.8
	36-in trestle	6/25/2020	S-2 (Bent 1)	159	15.0
	48-in permanent (attenuated)	6/10/2020	A-1	169	12.2
		6/12/2020	E-1	172	15.4
		6/12/2020	B-2	167	15.2
		6/14/2020	HT-2	164	13.1
	48-in permanent (unattenuated)	6/16/2020	B-1	174	18.2
			Range of values:	**159 to 174**	**12.2 to 18.2**
			Average:	**166**	**15.1**
High Tide	24-inch trestle	6/10/2020	S-3 (Bent 3)	160	13.5
		6/10/2020	S-1 (Bent 3)	166	14.6
	36-in trestle	6/16/2020	S-5 (Bent 2)	161	14.7
	48-in permanent (attenuated)	6/10/2020	D-1	165	8.8
		6/14/2020	C-2 (drift 1)	167	12.2
		6/14/2020	C-2 (drift 2)	162	10.8
		6/23/2020	B-5	165	14.5
			Range of values:	**160 to 167**	**8.8 to 14.7**
			Average:	**164**	**12.7**

6.11 Impact Driving RMS Pulse Duration

The RMS sound pressure level 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. However, this measurement program did not reveal any relationship of pulse duration with distance from the pile. In fact, pulse durations at the farthest measurement point tended to be shorter than pulses measured much closer to the pile, as shown on Figure 6-18. Assuming constant energy, a shorter pulse results in a higher RMS sound pressure level.

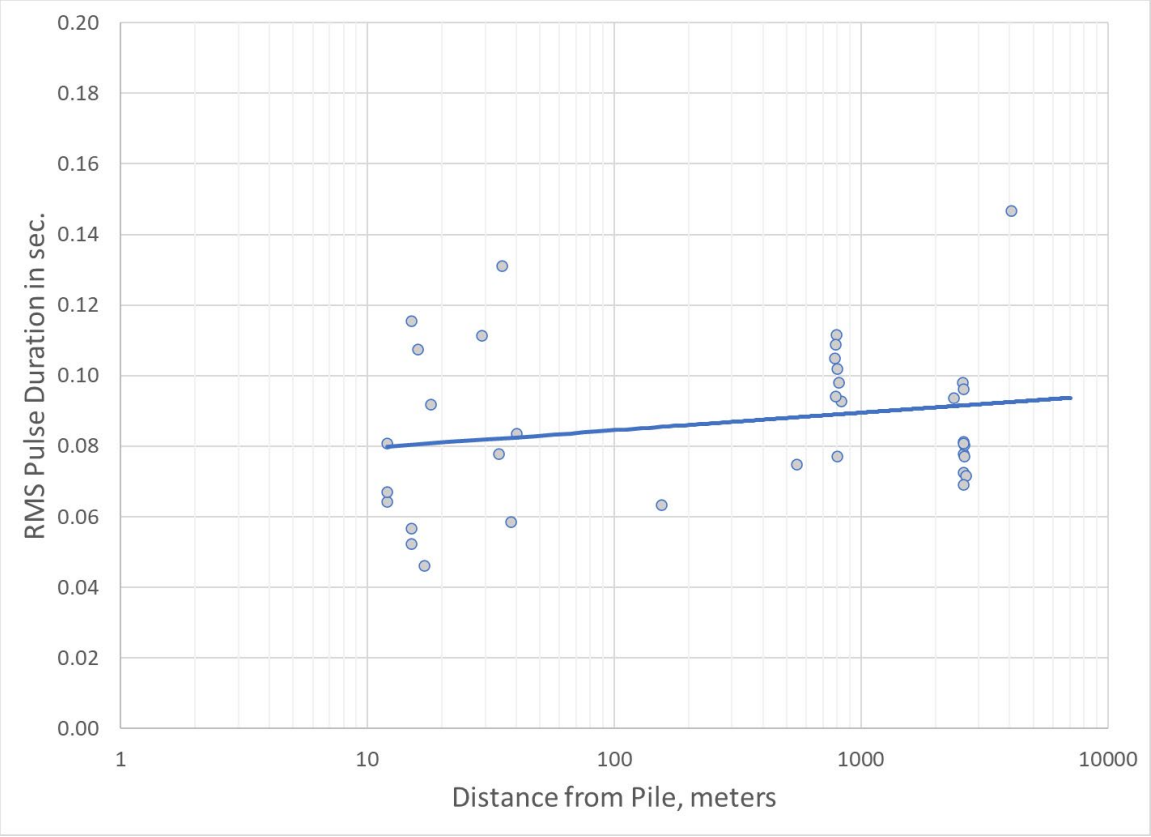


Figure 6-18. Pulse duration in seconds for RMS sound pressure level computation plotted by distance

6.12 Flow Noise Effects

Conducting underwater sound measurements in the Knik Arm is challenging due to the high current velocities. Strong currents cause flow effects that result in elevated low-frequency sound, with greatest effects below 50 Hz. During the strongest currents, this effect extended upward to about 100 Hz.

Figure 6-19 presents a spectrograph of sound levels over time, as measured by JASCO (Austin et al. 2016). The measurements were conducted over a 3-day period during the Memorial Day weekend in 2016. Ambient noise was described as follows:

- Dredging sounds caused elevated sound levels during the first day (May 28);

- Periodic elevated sound levels between 10 and 100 Hz were caused by flow or system noise generated during maximum tidal current flows;
- Brief peaks of broadband sound were suspected to be caused by tug activities associated with the arrival and departure of vessels using the Port; and
- There was no apparent diurnal pattern to the sound environment.

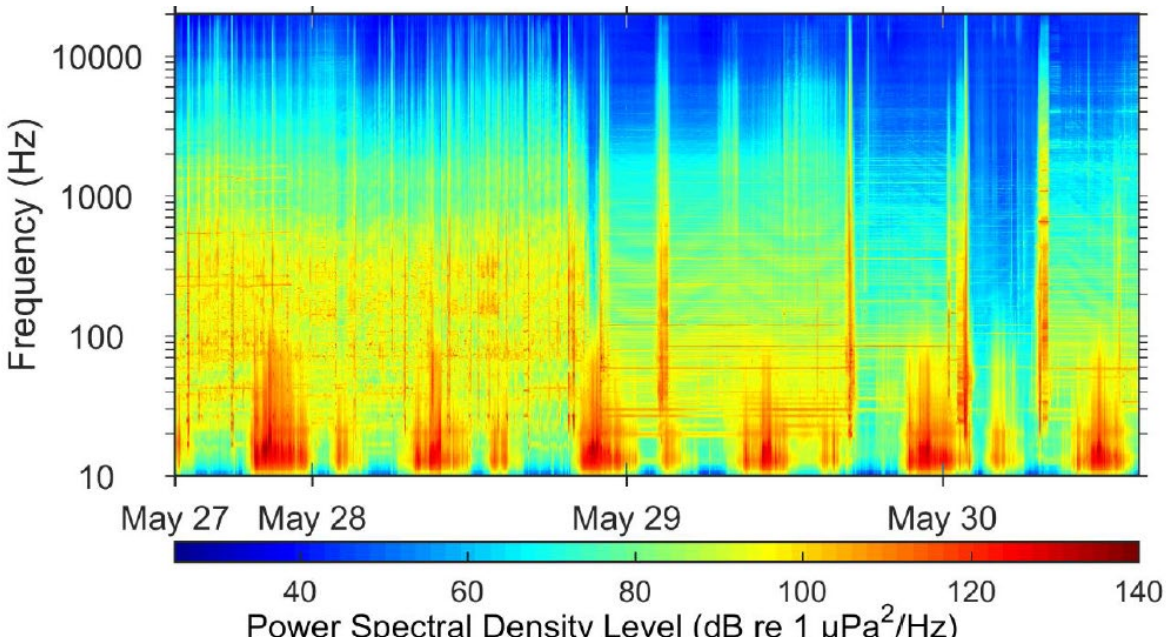


Figure 6-19. Background sound levels recorded by JASCO on May 27-May 30, 2016, at a location in the Cook Inlet offshore from the Port (Source: Austin et al. 2016)

Noise from current flows is present at least half of the time. This noise could affect measured piling sounds if the measured amplitude level is within 10 dB of the background sound. To accommodate for this effect, measured background sound levels were logarithmically subtracted from the measured levels. In addition, flow noise mainly affected sound levels below approximately 20 Hz. Spectrographs, provided in Appendix C, were examined further to identify measurements that may have been excessively affected by flow noise or other background sounds. Flow noise only increases sounds 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 background noise. Recommendations were suggested to further account for flow noise effects.

One suggestion was to analyze only the clear portions of the signal. This approach was rejected because it would bias the data set toward a louder level, as the quieter portions would be discarded. Vibratory driving sound levels vary by more than 10 dB during a single driving event. In addition, this would require the analyst to arbitrarily select pile-driving periods to discard.

Another recommendation was to use a higher cutoff frequency to eliminate low-frequency sound. 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 and below that frequency. As pointed out in Section 6.9, very low-frequency sounds in the 25- and 50-Hz bands were dominant for attenuated vibratory driving of 48-inch piles. Analyzing these data with a higher cutoff

frequency where these low-frequency sounds are present would eliminate sound content from the piling activity.

Table 6-23 provides a summary of the sound levels and transmission losses for vibratory pile installation when applying the higher frequency cutoffs of 50 and 100 Hz. These cutoffs were applied only to 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. The greatest effect is on the attenuated 48-inch piles, where Level B zones would be reduced to 5.0 to 7.2 km from 23.7 to 35.8 km. An ambient level of 122.2 dB was used, based on broadband sound measurements. That sound environment was likely most influenced by very low-frequency sound. The lower Level B threshold should be applied when comparing sound with a higher low-frequency cutoff (i.e., 50 and 100 Hz). Arbitrarily applying these cutoffs to certain piling events that are suspected of contamination by background sound or noise would not be appropriate for many of these piling events because of the low-frequency content associated with vibratory pile driving. This, as pointed out in Section 6.9, is considerable for 48-inch piles with the bubble casing attenuation system.

Table 6-23. Comparison of sound levels using different low-frequency cutoffs for attenuated vibratory pile installation

Pile Condition		Median RMS Level for 20 to 20,000 Hz	Median RMS Level for 50 to 20,000 Hz	Median RMS Level for 100 to 20,000 Hz
Vibratory 24-inch Template	TL (Log_{10}[distance])	14.1	13.5	13.9
	RMS 10m Level	158.5 dB	156.5 dB	156.4 dB
	Distance to 122.2 dB	3.8 km	3.5 km	2.9 km
	Distance to 120.0 dB	5.4 km	5.1 km	4.2 km
Vibratory 24-inch Trestle	TL (Log_{10}[distance])	15.0	14.4	14.4
	RMS 10m Level	162.8 dB	160.5 dB	159.4 dB
	Distance to 122.2 dB	5.1 km	4.6 km	3.8 km
	Distance to 120.0 dB	7.1 km	6.5 km	5.4 km
Vibratory 24-inch Trestle	TL (Log_{10}[distance])	14.3	14.4	14.1
	RMS 10m Level	161.4 dB	160.8 dB	158.9 dB
	Distance to 122.2 dB	5.5 km	4.8 km	4.0 km
	Distance to 120.0 dB	7.9 km	6.8 km	5.7 km
Vibratory 48-inch Trestle/Platform	TL (Log_{10}[distance])	13.0	13.2	13.5
	RMS 10m Level	166.2 dB	161.8 dB	158.6 dB
	Distance to 122.2 dB	23.7 km	10.0 km	5.0 km
	Distance to 120.0 dB	35.8 km	14.7 km	7.2 km
Unattenuated Vibratory 48-inch Trestle	TL (Log_{10}[distance])	18.2	18	18.5
	RMS 10m Level	174.0 dB	170.9 dB	170.4 dB
	Distance to 122.2 dB	7.0 km	5.1 km	4.0 km
	Distance to 120.0 dB	9.3 km	6.7 km	5.3 km

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 sound environment 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.

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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 and Cameron Heyvaert with support from Brett Carrothers, Leslie Curran, and Suzann Speckman. Numerous other HDR personnel provided support during this field effort, including Kevin Doyle and Paul McLarnon with project management and Brian Hessert and Alex Herlant with field support, and Tina Adair with document finalization. Carrie Janello, assisted by James Reyff and Cameron Heyvaert, led the data analysis effort and drafting of the report. The final report was reviewed by Paul Donavan. 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 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 unit of pressure. It is equivalent to 1 Newton per square meter. There are 1,000,000 microPascals in one 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 the 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 sound level meters 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 one 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 (1µPa^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 a sound level meter.

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 Piles and Casings and Pile Removal

NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

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Table A-1. Daily data summary for vibratory pile driving activities on June 9, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
15:28 to 15:47	D-1 Air Bubble Curtain Casing	APE 300-6	8.3 minutes	27	6	9	17	171	165	165	179	155	151	151
				135	6		17	157	153	153	167	142	140	139
				690	28		30	152	143	143	159	138	132	132
				2,335	20		22	143	135	135	146	125	118	119
16:00 to 16:29	S-5 (36-inch, Bent 3)		25.6 minutes	55	6	4	12	180	168	168	188	163	154	153
				145	6		10	172	161	158	179	153	145	144
				690	23		25	162	153	152	174	148	141	141
				2,335	15		17	152	142	141	163	139	130	129

Table A-2. Supplementary matched data taken from drifting vessel on June 9, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
16:02 to 16:29	S-5 (36-inch, Bent 3)	APE 300-6	25.4 minutes	55	6	4	12	180	168	168	163	154	153
				638	10		25	166	154	153	145	139	138
				690	23		25	162	153	152	148	141	141
				2,335	15		17	152	142	141	139	130	129

Table A-3. Daily data summary for vibratory pile driving activities on June 10, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
8:51 to 8:57	A-1 (48-inch)	APE 300-6	4.7 minutes	12	6	18	18	177	174	173	191	170	167	167
				155	6		18	161	156	156	171	149	147	147
				545	29		31	160	157	156	175	153	150	150
				2,355	21		23	150	146	146	162	140	138	138
9:06 to 9:23	S-4 (24-inch)		11.2 minutes	15	13	11	15	187	175	175	193	171	164	163
				55	6		19	181	168	168	192	161	152	152
				140	6		19	170	153	153	174	157	140	140
				590	30		32	157	148	148	175	149	137	137
				2,400	22		24	150	144	143	164	139	130	130
9:39 to 9:45	D-1 (48-inch)		5 minutes	29	6	16	20	183	169	170	193	166	160	161
				155	6		20	170	157	158	176	154	145	146
				565	31		33	162	158	157	180	155	153	152
				2,370	23		25	152	148	148	167	143	142	141
10:37 to 10:49	S-3 (24-inch)		11.8 minutes	11	13	12	15	196	177	177	198	175	159	163
				55	6		19	182	164	166	194	163	150	152
				146	6		19	167	155	156	178	153	141	143
				590	30		32	158	148	149	180	147	139	140
				2,400	22		24	148	137	139	168	137	126	128
11:46 to 12:00	S-1 (24-inch)		4.5 minutes	14	14	11	16	187	180	179	199	169	165	163
				58	6		20	176	167	166	194	158	153	151

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
				157	6		20	164	159	158	179	149	143	142
				590	31		33	156	151	151	180	143	141	140
				2,400	23		25	146	142	142	168	134	131	130

Table A-4. Daily data summary for vibratory pile driving activities on June 12, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
10:28 to 10:34	E-1 (48-inch)	APE 300-6	5.2 minutes	34	6	12	18	172	163	164	184	163	155	156
				150	6		18	159	149	150	167	147	137	139
				798	34		36	161	153	154	175	154	146	147
				2,584	19		21	143	135	136	154	134	126	127
16:11 to 16:16	B-2 (48-inch)		4 minutes	18	6	14	16	184	171	171	188	165	162	162
				152	6		16	171	156	157	172	152	146	147
				781	32		34	158	154	154	176	150	147	147
				2,568	17		19	152	140	140	157	134	129	129
17:35 to 17:56	T-13 (24-inch)	APE 200-6	19.2 minutes	5	10	8	12	184	173	172	192	169	160	159
				144	6		14	178	157	158	176	151	141	141
				824	30		32	157	144	145	177	144	133	134
				2,608	15		17	147	138	138	159	134	124	125
18:37 to 19:06	T-14 (24-inch)		21.3 minutes	18	9	5	11	178	168	165	193	161	154	151
				131	6		13	176	155	158	180	157	140	142
				827	29		31	156	147	146	177	144	135	135

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
				2,606	14		16	151	139	139	162	136	127	126

Table A-5. Supplementary matched data taken from drifting vessel on June 12, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
10:30 to 10:34	E-1 (48-inch)	APE 300-6	3.7 minutes	34	6	12	12	172	169	166	163	161	158
				312	10		20	159	157	154	154	152	149
				798	31		36	161	156	154	154	147	148
				2,584	19		21	143	138	137	134	130	128
16:14 to 16:16	B-2 (48-inch)		1.1 minutes	18	6	14	14	179	171	172	163	162	162
				781	32		34	155	153	153	147	146	146
				1,438	10		26	149	145	145	129	128	128
				2,568	17		19	145	141	141	131	130	129

Table A-6. Daily data summary for vibratory pile driving activities on June 14, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
11:12 to 11:21	C-2 Air Bubble Curtain Casing	ICE 44-B	7.8 minutes	12	13	12	15	173	165	165	180	160	154	153
				23	6		15	170	165	165	179	157	152	152
				144	6		15	161	156	156	167	146	141	141
				2,611	12		14	142	136	136	149	126	122	122
13:27 to 13:36	HT-2 (48-inch)	APE 300-6	9.2 minutes	12	12	10	15	180	169	170	194	174	163	164
				50	17		19	165	155	156	182	153	147	147

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
				137	6		19	158	153	153	174	150	145	145
				2,650	16		18	143	139	140	158	136	131	131
13:54 to 14:06	C-2 (48-inch)		10 minutes	12	17	16	19	186	173	173	191	171	161	162
				23	6		19	186	170	171	190	169	160	161
				144	6		19	167	159	159	179	151	149	149
				789	29		31	173	160	160	180	158	149	148
				2,611	16		18	150	143	143	163	137	133	133
16:06 to 16:13	A-2 Air Bubble Curtain Casing	ICE 44-B	3.9 minutes	13	6	18	19	170	161	162	190	154	149	149
				146	6		19	154	148	148	179	142	136	136
				777	29		31	159	151	152	180	147	139	139

Table A-7. Supplementary matched data taken from drifting vessel on June 14, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
13:28 to 13:33	HT-2 (48-inch)	APE 300-6	4.9 minutes	12	12	10	15	180	173	172	174	167	167
				50	17		19	165	156	157	153	148	149
				910	10		27	154	148	148	145	140	140
				2,650	16		18	143	139	140	136	132	132
13:54 to 13:56	C-2 (48-inch)		1.9 minutes	12	17	16	19	186	177	177	171	165	166
				23	6		19	186	175	176	169	164	164
				544	10		27	164	155	155	148	144	144

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
				789	29		31	173	162	163	158	150	151
				2,611	16		18	149	144	144	137	135	134
14:03 to 14:06	C-2 (48-inch)		2.2 minutes	12	14	16	16	181	172	172	164	160	161
				23	6		16	180	170	170	161	160	160
				480	10		27	154	149	149	141	140	140
				789	29		31	166	160	160	151	148	148
				2,611	16		18	147	143	143	136	134	133

Table A-8. Daily data summary for vibratory pile driving activities on June 16, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
8:31 to 8:58	T-15 (24-inch)	APE 200-6	25.6 minutes	29	9	10	11	180	171	169	189	164	155	154
				48	6		15	172	160	161	182	158	147	148
				127	6		15	164	154	155	174	149	141	141
				2,620	14		16	146	137	137	156	132	122	123
9:58 to 10:18	T-16 (24-inch)		24 minutes	41	7	7	9	179	164	165	190	163	150	150
				52	6		13	178	165	166	186	160	150	150
				141	6		13	176	158	158	177	151	142	142
				823	24		26	156	147	147	169	140	133	133
				2,618	10		14	145	135	136	159	132	122	123
14:28 to 14:46	B-1* (48-inch)	APE 300-6	15 minutes	16	6	14	19	197	183	182	198	176	167	167
				53	13		15	188	172	173	193	170	159	160

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
				151	6		19	177	162	163	183	160	149	150
				2,588	18		20	151	141	141	162	137	130	130
16:47 to 17:28	S-5 (36-inch, Bent 2)		36.4 minutes	31	13	13	15	190	170	170	196	170	157	157
				44	6		17	179	162	162	198	161	149	149
				143	6		17	171	155	155	184	153	142	143
				815	30		32	157	147	147	175	142	133	136
				2,616	18		20	150	138	139	165	139	127	127

*Pile B-1 was unattenuated on June 16, 2020.

Table A-9. Supplementary matched data taken from drifting vessel on June 16, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
8:31 to 8:57	T-15 (24-inch)	APE 200-6	25 minutes	29	9	10	11	180	171	169	164	155	154
				48	6		15	172	159	160	158	147	148
				263	10		20	164	150	151	144	139	139
				2,620	14		16	146	136	137	132	122	123
14:30 to 14:39	B-1* (48-inch)	APE 300-6	7 minutes	16	6	7	19	196	185	182	175	170	167
				53	13		15	185	177	174	168	162	160
				716	10		26	161	155	155	144	139	138
				2,588	18		20	151	143	142	136	131	130
16:54 to 17:28	S-5 (36-inch,		32.8 minutes	31	9	17	11	190	170	170	170	157	157
				44	6		13	179	162	162	161	149	149

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
	Bent 2)			514	10		27	159	152	152	142	134	135
				815	30		32	157	147	147	142	133	134
				2,616	18		20	150	138	139	139	127	127

Table A-10. Daily data summary for vibratory pile driving activities on June 17, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
13:21 to 14:01	S-2 (36-inch, Bent 2)	APE 300-6	36 minutes	25	7	7	9	195	175	174	197	176	161	160
				154	6		11	172	157	157	177	155	140	141
				807	23		25	167	148	148	172	148	136	137
				2,623	12		14	154	145	145	163	141	128	128
16:01 to 16:14	S-1 (24-inch)		10.8 minutes	25	12	11	14	190	177	177	198	170	161	161
				157	6		16	168	155	156	178	152	142	142
				807	28		30	159	151	151	173	143	136	137
				2,623	17		19	149	141	141	164	134	126	126

Table A-11. Supplementary matched data taken from drifting vessel on June 17, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
13:25 to 14:01	S-2 (36-inch, Bent 2)	APE 300-6	35.5 minutes	25	7	7	9	195	175	174	176	161	160
				335	10		20	179	154	155	155	140	140
				807	23		25	167	148	148	148	136	137
				2,623	12		14	154	145	145	141	128	128

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
16:04 to 16:14	S-1 (24-inch)		9.1 minutes	25	12	11	14	190	178	178	170	161	162
				475	10		25	165	153	153	142	135	136
				807	28		30	159	151	151	143	137	137
				2,623	17		19	149	141	141	134	126	127

Table A-12. Daily data summary for vibratory pile driving activities on June 19, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
12:27 to 12:44	E-4 (48-inch)	APE 300-6	10.1 minutes	15	10	7	12	196	172	173	192	176	159	159
				38	6		12	187	161	163	185	168	151	151
				132	6		12	171	150	151	170	154	139	138
				810	23		25	160	149	149	168	148	139	138
				2,595	11		13	154	140	140	158	139	129	128

Table A-13. Supplementary matched data taken from drifting vessel on June 19, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
12:31 to 12:44	E-4 (48-inch)	APE 300-6	9.4 minutes	15	10	7	12	196	172	173	176	159	159
				38	6		12	187	164	165	168	154	153
				461	10		20	171	150	151	150	139	139
				810	23		25	160	149	149	148	139	138
				2,595	11		13	154	139	139	139	128	128

Table A-14. Daily data summary for vibratory pile driving activities on June 20, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
14:28 to 14:40	GT-3 (48-inch)	APE 300-6	7.7 minutes	17	8	5	10	193	187	186	198	176	172	170
				55	6		12	187	180	179	192	171	165	164
				148	6		18	178	169	168	181	158	154	154
				2,616	16		18	157	151	152	166	146	139	140
16:09 to 16:12	D-5 Air Bubble Curtain Casing	ICE 44-B	3.1 minutes	14	12	10	14	167	165	165	174	154	152	151
				118	6		20	160	157	157	181	143	139	139
16:22 to 16:25	E-5 Air Bubble Curtain Casing		0.6 minutes	20	12	10	14	177	165	165	175	154	150	150
				121	6		20	157	155	155	181	143	141	141
				2,601	18		20	138	134	134	166	123	121	121

Table A-15. Supplementary matched data taken from drifting vessel on June 20, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
14:32 to 14:39	GT-3 (48-inch)	APE 300-6	6.9 minutes	17	8	5	10	193	188	188	176	172	172
				55	6		12	187	180	180	171	165	166
				339	10		15	169	166	166	157	152	152
				2,616	16		18	157	151	152	146	139	140

Table A-16. Daily data summary for vibratory pile driving activities on June 23, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
	B-5	APE 300-6	9.8 minutes	15	6	19	21	180	169	169	190	166	162	162

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
8:32 to 8:44	(48-inch)			125	19		21	164	153	153	169	149	140	140
				800	35		37	161	147	147	165	142	137	137

Table A-17. Daily data summary for vibratory pile driving activities on June 24, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
14:30 to 14:37	S-3 (24-inch)	APE 300-6	7.8 minutes	13	12	9	14	183	169	170	186	166	157	157
				150	6		14	163	152	153	167	146	139	139
				2,620	18		20	147	139	139	151	130	125	124
15:25 to 15:35	S-1 (24-inch)		9.6 minutes	16	11	8	13	185	167	166	187	163	155	154
				159	6		13	164	152	152	170	144	140	139
				2,620	17		19	144	136	136	154	128	124	124
16:16 to 16:52	36" Pin Removal		33.4 minutes	9	10	mud	12	189	163	166	191	161	153	153
				141	6		12	165	154	154	175	147	139	139
				2,635	16		18	149	135	135	158	132	122	122
16:47 to 16:59	B-4 (48-inch)		8 minutes	40	10	10	12	186	164	166	191	169	151	152
				133	6		12	180	161	162	179	162	149	149
				2,605	16		18	152	139	139	160	135	128	127
17:06 to 17:37	S-5 (36-inch, Bent 1)		31.5 minutes	14	10	6	12	191	169	169	195	175	156	156
				143	6		12	166	156	156	181	156	142	142
				2,615	16		18	149	137	137	162	139	124	124

Table A-18. Supplementary matched data taken from drifting vessel on June 24, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean	Max	Median	Mean
15:25 to 15:35	S-1 (24-inch)	APE 300-6	9.6 minutes	16	11	8	13	185	167	166	163	155	154
				553	10		20	180	152	152	154	132	131
				2,620	17		19	140	136	136	128	124	124
17:08 to 17:27	S-5 (36-inch, Bent 1)		18.9 minutes	14	10	6	12	191	168	169	175	155	156
				205	10		14	184	183	155	164	141	143
				2,615	16		18	149	136	137	139	123	124

Table A-19. Daily data summary for vibratory pile driving activities on June 25, 2020

Time	Pile ID	Hammer Type	No. of Strikes or Duration	Distance to Pile from Hydrophone (m)	Hydrophone Depth (m)	Water Depth (m)		Peak (dB)			cSEL (dB)	RMS (dB)		
						Pile	Hydrophone	Max	Median	Mean		Max	Median	Mean
12:23 to 12:45	S-2 (36-inch)	APE 300-6	22.1 minutes	10	6	14	14	197	170	171	192	169	159	160
				155	6		19	164	154	154	172	148	140	140
				190	6		19	160	153	153	175	148	144	143

Appendix B

Summary Data Tables for Impact Pile Driving

NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

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Table B-1. Daily data summary for impact pile driving activities on June 10, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (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
11:30 to 11:56	D-1	DELMAG D-180	950 strikes	29	6	16	20	198	191	191	174	167	167	198	185	177	178	0.1695	0.1115	0.1114
				155	18		20	194	191	190	169	165	164	195	179	177	177	0.0838	0.0635	0.0619
				565	31		33	185	180	180	161	158	157	188	174	170	170	0.1882	0.0811	0.0849
				2,370	23		25	174	169	169	154	148	148	176	164	159	159	0.1757	0.0938	0.0968
14:35 to 15:34	A-1		1,021 strikes	12	6	14	16	206	202	202	178	175	175	206	189	187	186	0.1694	0.0808	0.8240
				155	14		16	197	196	194	172	169	167	200	185	183	183	0.0824	0.0429	0.0491
				545	27		29	182	181	181	162	160	158	192	175	173	173	0.1045	0.0749	0.0757
				4,050	19		21	156	154	152	140	135	134	176	150	143	143	0.1840	0.1467	0.1470

Table B-2. Supplementary matched data taken from drifting vessel on June 10, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
14:37 to 14:40	A-1	DELMAG D-180	149 strikes	12	6	14	16	201	198	198	177	176	175	188	187	186	0.1002	0.0848	0.0857
				545	27		29	181	181	181	162	160	158	175	173	173	0.1028	0.0834	0.0848
				2,025	10		19	169	167	166	148	146	145	159*	157*	157*	0.2457	0.1886	0.1911
				4,050	19		21	156	155	155	138	136	135	145	144	144	0.1608	0.1438	0.1443
15:17 to 15:28	A-1		647 strikes	12	6	14	16	206	204	203	178	176	175	189	187	187	0.1694	0.0756	0.0817
				545	27		29	182	181	181	162	160	158	175	174	173	0.0794	0.0671	0.0677
				2,783	10		17	168	160	160	145	137	137	157*	149*	149*	0.2774	0.2493	0.2439
				4,050	19		21	155	153	151	140	135	134	150	143	143	0.1769	0.1575	0.1535

*RMS levels reported here were from the SLM meter.

Table B-3. Daily data summary for impact pile driving activities on June 12, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (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
11:33 to 12:04	E-1	DELMAG D-180	1,101 strikes	34	6	13	19	200	192	191	175	167	167	199	187	181	180	0.1391	0.0779	0.0820
				150	6		19	193	191	189	168	164	163	195	181	179	178	0.0991	0.0482	0.0510
				798	35		37	182	179	179	161	157	156	188	160	157	157	0.1533	0.0978	0.1020
				2,584	20		22	173	169	169	152	147	147	174	164	160	160	0.1156	0.0725	0.0716
16:42 to 16:51	B-2 (part)		231 strikes	18	6	13	15	201	197	197	176	175	174	202	187	185	185	0.1055	0.0918	0.0917
				152	6		15	195	193	193	173	169	168	197	185	181	181	0.0965	0.0721	0.0728
				781	31		33	182	182	181	163	161	160	189	173	171	171	0.1198	0.1045	0.1050
				2,568	16		18	173	171	171	153	151	150	176	163	162	161	0.1308	0.0982	0.0992

Table B-4. Supplementary matched data taken from drifting vessel on June 12, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
11:37 to 11:51	E-1	DELMAG D-180	630 strikes	34	6	13	19	200	194	194	175	170	169	187	183	183	0.1012	0.0686	0.0697
				798	35		37	182	181	180	161	158	156	170	168	168	0.1465	0.1090	0.1075
				1,161	10		26	177	174	174	156	152	151	167*	164*	164*	0.2470	0.1100	0.1129
				2,584	20		22	173	170	170	152	149	148	164	161	161	0.0915	0.0716	0.0711
11:56 to 12:00	E-1		310 strikes	34	6	13	19	189	187	187	166	165	164	176	175	175	0.1334	0.1040	0.1056
				798	35		37	179	178	178	158	157	156	167	166	166	0.1008	0.0951	0.0946
				1,636	10		28	174	166	166	146	144	143	168*	155*	155*	0.2740	0.2193	0.2010
				2,584	20		22	168	166	166	148	146	146	160	159	158	0.0750	0.0726	0.0723

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
16:45 to 16:50	B-2 (partial)		231 strikes	18	6	15	15	201	197	197	176	175	174	187	185	185	0.1055	0.0918	0.0917
				781	31		33	182	182	181	163	161	160	173	171	171	0.1198	0.1045	0.1050
				1,778	10		23	173	170	170	153	150	149	164*	160*	160*	--	--	--
				2,568	16		18	173	171	171	153	151	150	163	162	161	0.1308	0.0982	0.0992

*RMS levels reported here were from the SLM meter. No wav files available for pulse analysis of drift data during Pile B-2.

Table B-5. Daily data summary for impact pile driving activities on June 14, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (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
14:18 to 14:41	HT-2	DELMAG D-180	990 strikes	12	17	10	19	203	201	201	177	173	173	203	189	185	185	0.1177	0.0616	0.0643
				50	17		19	201	196	195	174	169	169	200	186	182	182	--	--	--
				137	6		19	198	194	194	179	174	171	204	191	186	187	0.0908	0.0530	0.0587
				827	29		31	191	183	184	166	160	160	191	177	171	171	0.1832	0.0928	0.0942
				2,650	16		18	176	171	170	154	149	148	179	165	162	161	0.1771	0.0717	0.0740
16:41 to 17:05	C-2		936 strikes	12	16	15	18	206	201	201	180	176	175	207	192	188	188	0.1138	0.0655	0.0671
				23	6		18	199	193	193	173	170	169	204	184	182	181	--	--	--
				144	6		18	201	195	195	182	174	172	207	197	187	188	0.1193	0.0480	0.0561
				793	28		30	187	182	183	165	161	160	194	175	171	170	0.2351	0.1057	0.1116

Table B-6. Supplementary matched data taken from drifting vessel on June 14, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
14:20 to 14:23	HT-2	DELMAG D-180	128 strikes	12	17	10	19	203	202	202	177	175	174	188	186	186	0.0925	0.0780	0.0784
				50	17		19	198	197	196	173	171	169	186*	183*	182*	--	--	--
				827	29		31	187	183	183	164	161	161	174	171	171	0.1330	0.1055	0.1078
				1,780	10		30	174	173	173	154	152	151	164	163	163	0.1186	0.0927	0.0944
				2,650	16		18	175	173	173	153	152	150	164	163	163	0.0743	0.0676	0.0680
14:24 to 14:27	HT-2		161 strikes	12	17	10	19	203	202	202	177	174	174	188	186	186	0.0827	0.0685	0.0695
				50	17		19	201	199	198	174	173	172	186*	185*	184*	--	--	--
				827	29		31	188	187	186	164	163	162	176	173	173	0.1087	0.0925	0.0919
				1,630	10		30	177	175	175	157	155	154	166	165	165	0.1432	0.1088	0.1079
				2,650	16		18	176	175	174	154	153	151	165	165	165	0.0808	0.0696	0.0706
16:53 to 16:57	C-2		188 strikes	12	16	15	18	206	201	202	180	177	176	192	188	188	0.0702	0.636	0.0632
				23	6		18	196	193	193	173	171	170	184*	182*	182*	--	--	--
				793	28		30	186	184	184	164	162	161	173	170	170	0.2202	0.1108	0.1245
				1,014	10		27	180	178	178	158	156	155	167	166	166	0.1339	0.1187	0.1164
16:58 to 17:02	C-2		205 strikes	12	16	15	18	203	201	201	177	174	173	188	185	185	0.1138	0.0752	0.0794
				23	6		18	196	192	192	170	169	168	182*	180*	180*	--	--	--
				793	28		30	183	181	181	161	160	159	170	168	168	0.1630	0.1214	0.1258
				1,110	10		27	175	173	173	155	152	152	164	161	162	0.1588	0.1300	0.1309

*RMS levels reported here were from the SLM meter. No wav files available for pulse analysis.

Table B-7. Daily data summary for impact pile driving activities on June 16, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (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
9:18 to 9:42	B-2	DELMAG D-180	757 strikes	15	6	13	14	201	195	195	178	173	172	201	189	182	182	0.1558	0.1163	0.1156
				146	6		14	204	198	198	177	171	169	199	189	186	185	0.0369	0.0283	0.0284
				788	25		27	177	173	173	156	152	151	180	167	162	162	0.1432	0.1122	0.1090
				2,586	13		15	173	168	168	152	147	146	152	164	158	158	0.0974	0.0779	0.0809
16:19 to 16:46	B-1		969 strikes	16	6	17	19	201	194	194	174	171	170	204	186	181	181	0.1651	0.1074	0.1041
				151	6		19	197	194	193	170	168	167	201	179	176	176	0.0697	0.0500	0.0497
				787	30		32	181	177	177	158	154	153	185	168	164	164	0.1244	0.0951	0.0942
				2,588	18		20	172	167	168	151	147	147	163	161	158	158	0.1250	0.0962	0.0951

Table B-8. Supplementary matched data taken from drifting vessel on June 16, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
9:25 to 9:42	B-2	DELMAG D-180	745 strikes	15	6	13	14	201	195	195	178	173	172	189	182	182	0.1558	0.1163	0.1156
				788	25		27	177	173	173	156	152	151	167	162	162	0.1432	0.1122	0.1090
				1,503	10		25	177	170	170	157	148	148	171	158	158	0.2491	0.1198	0.1209
				2,586	13		15	173	168	168	152	147	146	164	158	158	0.0974	0.0779	0.0809
16:23 to 16:46	B-1		872 strikes	16	6	17	19	199	194	194	173	171	170	186	181	181	0.1651	0.1074	0.1041
				787	30		32	181	177	177	157	154	153	168	164	164	0.1244	0.0951	0.0942
				1,544	10		27	176	170	170	155	149	149	174	159	159	0.2084	0.1234	0.1241
				2,588	18		20	172	167	168	151	147	147	161	158	158	0.1250	0.0962	0.0951

Table B-9. Daily data summary for impact pile driving activities on June 19, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (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
15:18 to 16:00	E-4	DELMAG D-180	1,211 strikes	15	12	9	14	210	200	200	181	174	174	206	195	186	187	0.0692	0.0567	0.0567
				38	6		14	203	197	197	179	172	171	204	192	185	185	0.1416	0.0553	0.0585
				132	6		14	194	187	188	168	162	161	194	184	180	179	0.0804	0.0544	0.0547
				810	25		27	189	181	181	166	160	159	192	176	171	171	0.1482	0.0980	0.0962
				2,595	13		15	174	172	172	153	150	149	180	164	163	162	0.1033	0.0701	0.0691

Table B-10. Supplementary matched data taken from drifting vessel on June 19, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
15:33 to 15:43	E-4	DELMAG D-180	439 strikes	15	12	9	14	206	202	202	179	176	175	191	188	188	0.0655	0.0514	0.0519
				38	6		14	202	199	199	177	175	173	190	189	188	0.0547	0.0460	0.0454
				810	25		27	183	180	180	162	160	159	172	170	170	0.1249	0.0991	0.1026
				1,247	10		28	178	175	175	157	154	152	173	163	162	0.1677	0.1046	0.1080
				2,595	13		15	174	171	172	153	151	149	164	163	163	0.0754	0.0700	0.0690
15:52 to 16:00	E-4		300 strikes	15	12	9	14	201	199	199	176	174	173	187	186	186	0.0679	0.0635	0.0633
				38	6		14	198	195	195	173	172	171	185	184	184	0.0838	0.0655	0.0665
				810	25		27	189	183	183	166	164	162	176	174	174	0.1482	0.0954	0.0950
				818	10		27	183	180	180	161	158	156	172	169	168	0.1360	0.0832	0.0879
				2,595	13		15	174	173	173	153	151	149	164	163	163	0.1033	0.0762	0.0756

Table B-11. Daily data summary for impact pile driving activities on June 20, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (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
15:32 to 16:00	GT-3	DELMAG D-180	968 strikes	17	10	6	12	207	205	204	183	179	178	209	195	192	191	0.0695	0.0461	0.0495
				148	6		20	202	196	196	175	170	169	201	184	179	178	0.0767	0.0407	0.0458
				2,616	18		20	178	173	172	155	149	149	180	167	164	161	0.1631	0.0805	0.0817

Table B-12. Supplementary matched data taken from drifting vessel on June 20, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
15:34 to 15:46	GT-3	DELMAG D-180	462 strikes	17	10	6	12	207	206	206	183	181	180	195	193	193	0.0695	0.0604	0.0583
				1,421	10		23	180	178	177	159	156	155	173	165	165	0.2025	0.1119	0.1204
				2,616	18		20	178	175	175	155	153	152	167	165	165	0.0841	0.0736	0.0735
15:55 to 16:00	GT-3		168 strikes	17	10	6	12	206	203	203	181	175	175	194	188	189	0.0534	0.0427	0.0428
				1,655	10		23	177	171	171	156	148	148	174	158	158	0.2203	0.1156	0.1190
				2,616	18		20	174	170	170	154	146	146	164	156	157	0.1538	0.0876	0.0914

Table B-13. Daily data summary for impact pile driving activities on June 23, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (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
9:43 to 10:18	B-5	DELMAG D-180	1,394 strikes	15	18	18	20	209	205	205	181	179	178	210	194	191	191	0.0802	0.0525	0.0561
				125	6		10	203	200	199	177	174	172	205	190	187	186	--	--	--
				800	34		36	185	184	183	163	161	160	192	179	172	172	0.1064	0.0773	0.0777
				2,600	16		18	176	173	173	154	152	151	182	165	163	163	0.1105	0.0793	0.0813

Table B-14. Supplementary matched data taken from drifting vessel on June 23, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
9:49 to 9:55	B-5	DELMAG D-180	273 strikes	15	18	18	20	207	204	204	180	178	177	192	190	190	0.0796	0.0610	0.0625
				800	34		36	185	184	183	163	161	160	174	173	172	0.0975	0.0712	0.0726
				1,624	10		30	177	174	174	156	153	151	172	160	160	0.2717	0.1340	0.1355
				2,600	16		18	176	173	173	154	152	151	165	163	163	0.1063	0.0814	0.0836

Table B-15. Daily data summary for impact pile driving activities on June 24, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (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
10:35 to 11:03	D-5	DELMAG D-180	1,133 strikes	35	18	16	20	196	191	191	172	168	167	198	188	177	177	0.2197	0.1311	0.1313
				125	6		20	195	191	191	170	167	166	197	178	175	175	0.0735	0.0500	0.0504
				2,620	24		26	176	172	172	154	150	150	179	166	162	162	0.1033	0.0767	0.0772
14:46 to 14:56	A-1		278 strikes	40	11	13	13	193	191	191	169	166	166	199	180	178	178	0.0889	0.0836	0.0834
				152	6		13	200	199	198	174	170	169	199	185	182	181	0.0280	0.02411	0.0239
				2,600	17		19	171	168	168	150	146	146	179	161	159	158	0.0985	0.0783	0.0808

Table B-16. Supplementary matched data taken from drifting vessel on June 24, 2020

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
10:38 to 10:54	D-5	DELMAG D-180	739 strikes	35	18	16	20	196	192	192	172	169	168	188	178	178	0.2197	0.1015	0.1184
				800	10		29	190	177	177	163	155	154	173	164	164	0.2945	0.0982	0.1128
				2,620	24		26	176	173	173	154	151	150	166	163	163	0.0937	0.0746	0.0748
	D-5			35	18	16	20	192	188	188	169	165	165	178	173	174	0.2134	0.1707	0.1530

Time	Pile ID	Hammer Type	No. of Strikes	Dist. to Pile from Hydro. (m)	Hydro. Depth (m)	Water Depth (m)		Peak (dB)			Single-Strike SEL (dB)			90% RMS (dB)			90% Pulse Duration (sec)		
						Pile	Hydro.	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
10:55 to 11:03			398 strikes	1,129	10		29	176	172	172	154	150	150	168	162	161	0.2453	0.1042	0.1019
				2,620	24		26	171	170	170	150	149	148	162	160	160	0.1033	0.0841	0.0807
14:51 to 14:54	A-1		97 strikes	40	11	13	13	193	190	190	169	165	165	180	176	177	0.0889	0.0855	0.0849
				1,459	10		24	177	168	168	152	147	146	161	155	155	0.2337	0.1325	0.1378
				2,600	17		19	169	168	167	150	146	146	160	159	159	0.088	0.0785	0.0807

Appendix C

Summary of Spectrograms for Each 24-, 36-, and 48-inch Pile During Vibratory Driving

NMFS Disclaimer: This report contains data from a complex environment . NMFS does not agree with all the approaches to this analysis and cautions application of these data to other locations.

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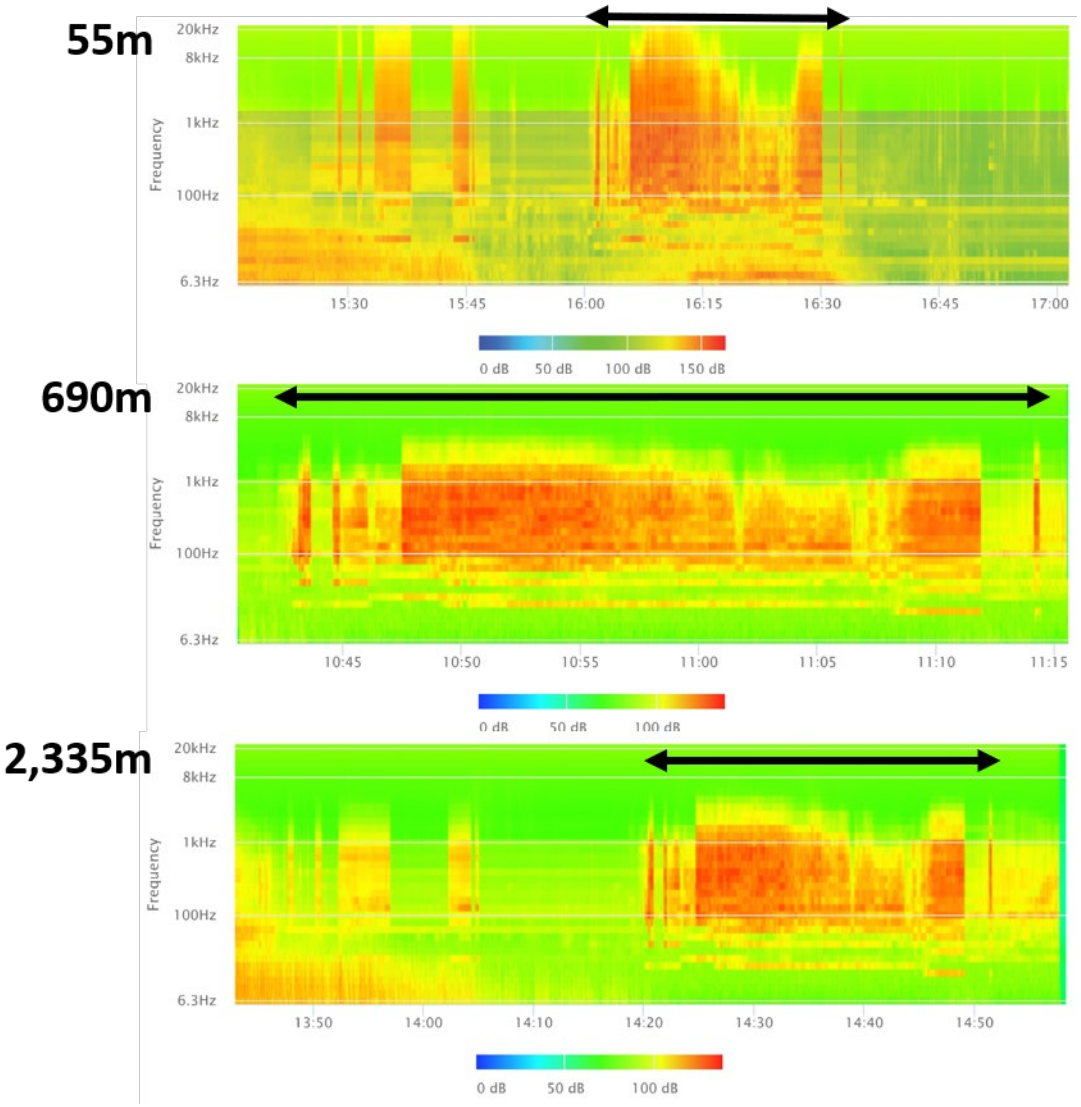

Figure C-1. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-5 on June 9, 2020

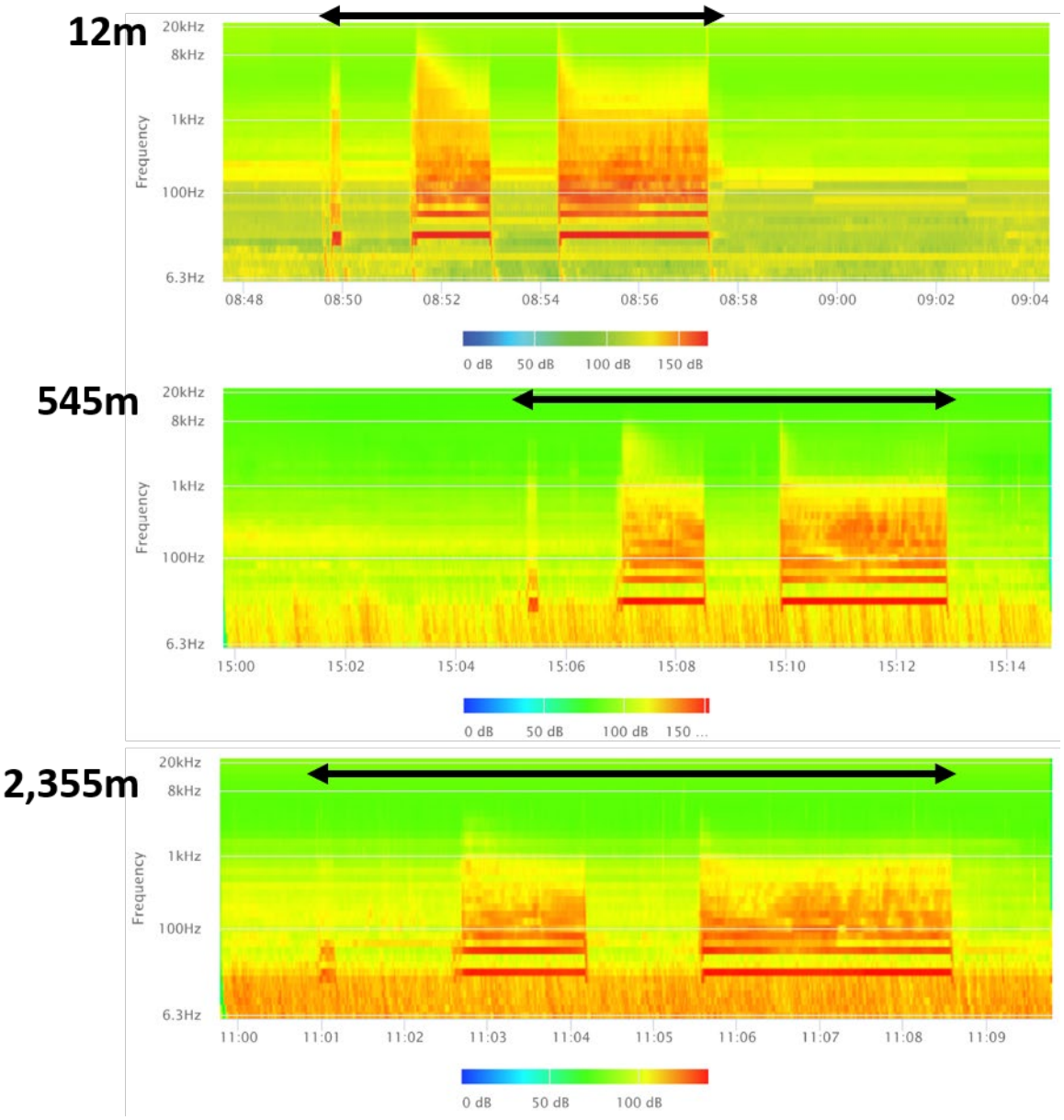

Figure C-2. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile A-1 on June 10, 2020

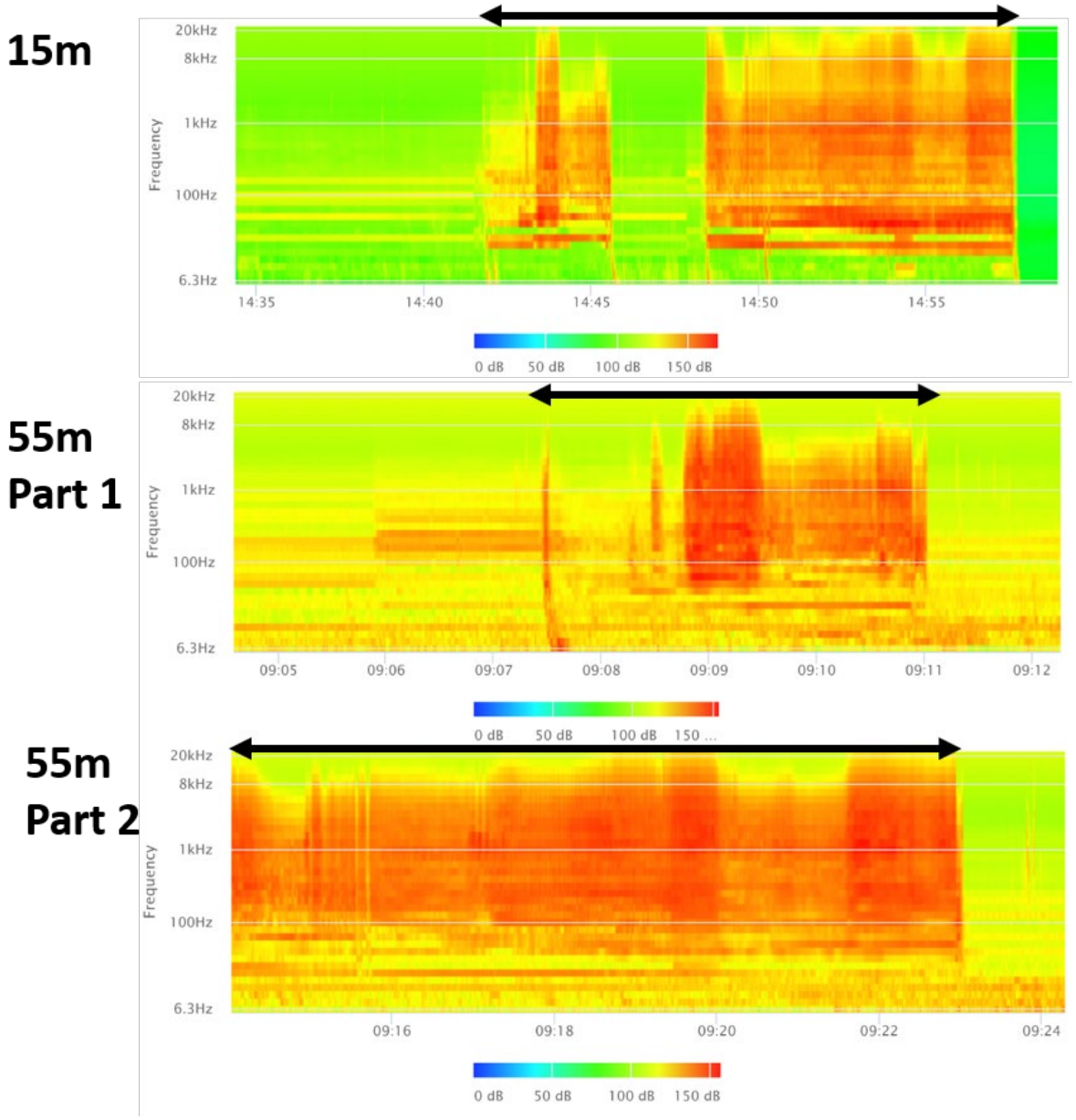

Figure C-3. Spectrogram plots for near field measurement locations in the westward direction during the vibratory driving of Pile S-4 on June 10, 2020

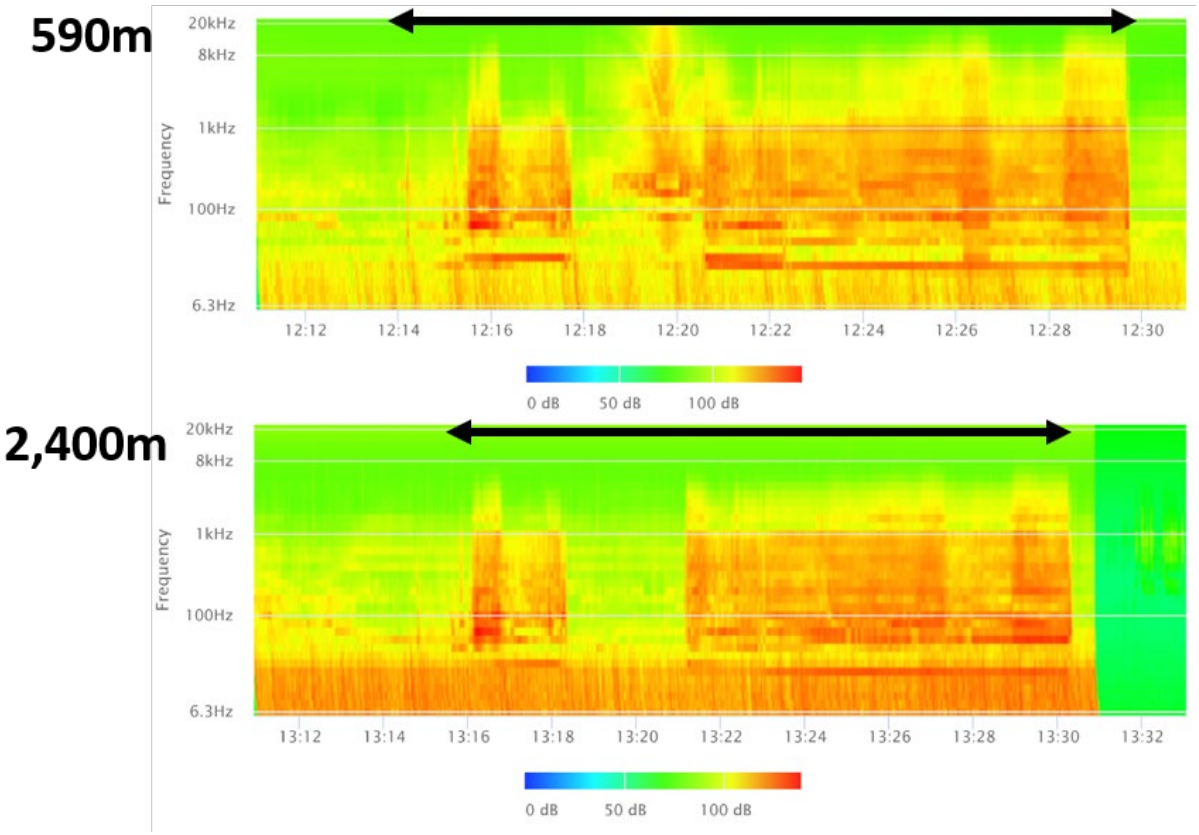

Figure C-4. Spectrogram plots for far field measurement locations in the westward direction during the vibratory driving of Pile S-4 on June 10, 2020

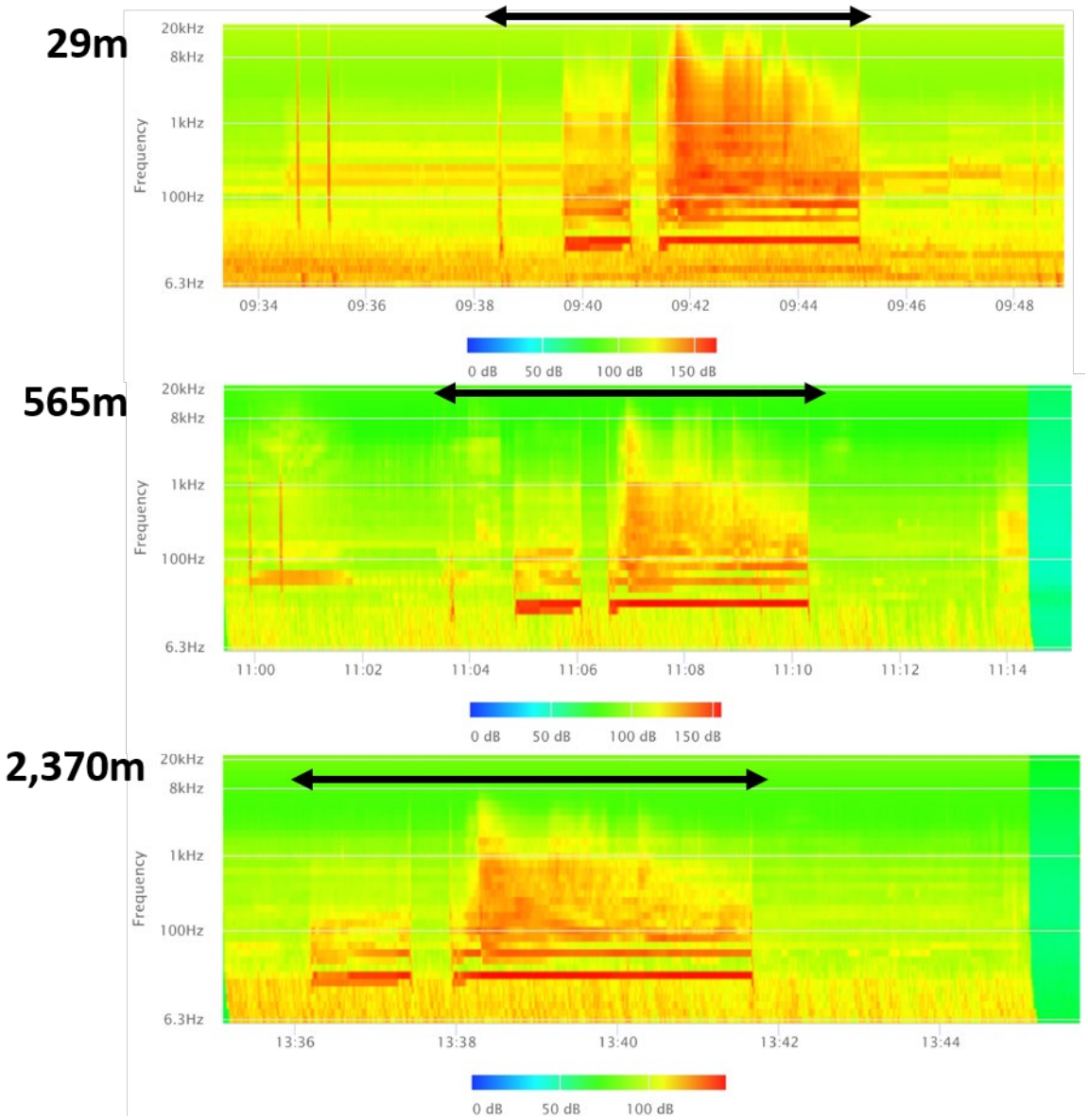

Figure C-5. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile D-1 on June 10, 2020

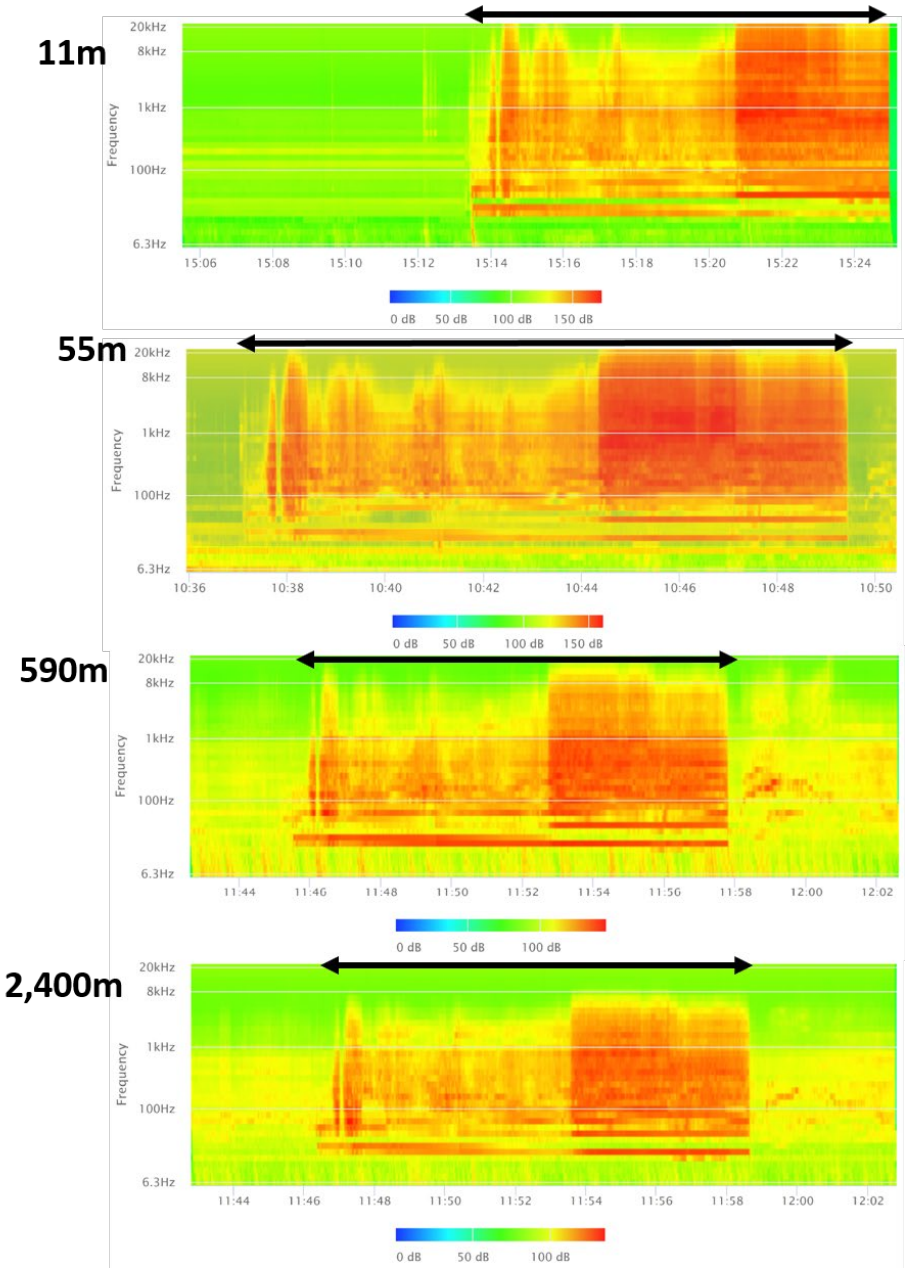

Figure C-6. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-3 on June 10, 2020

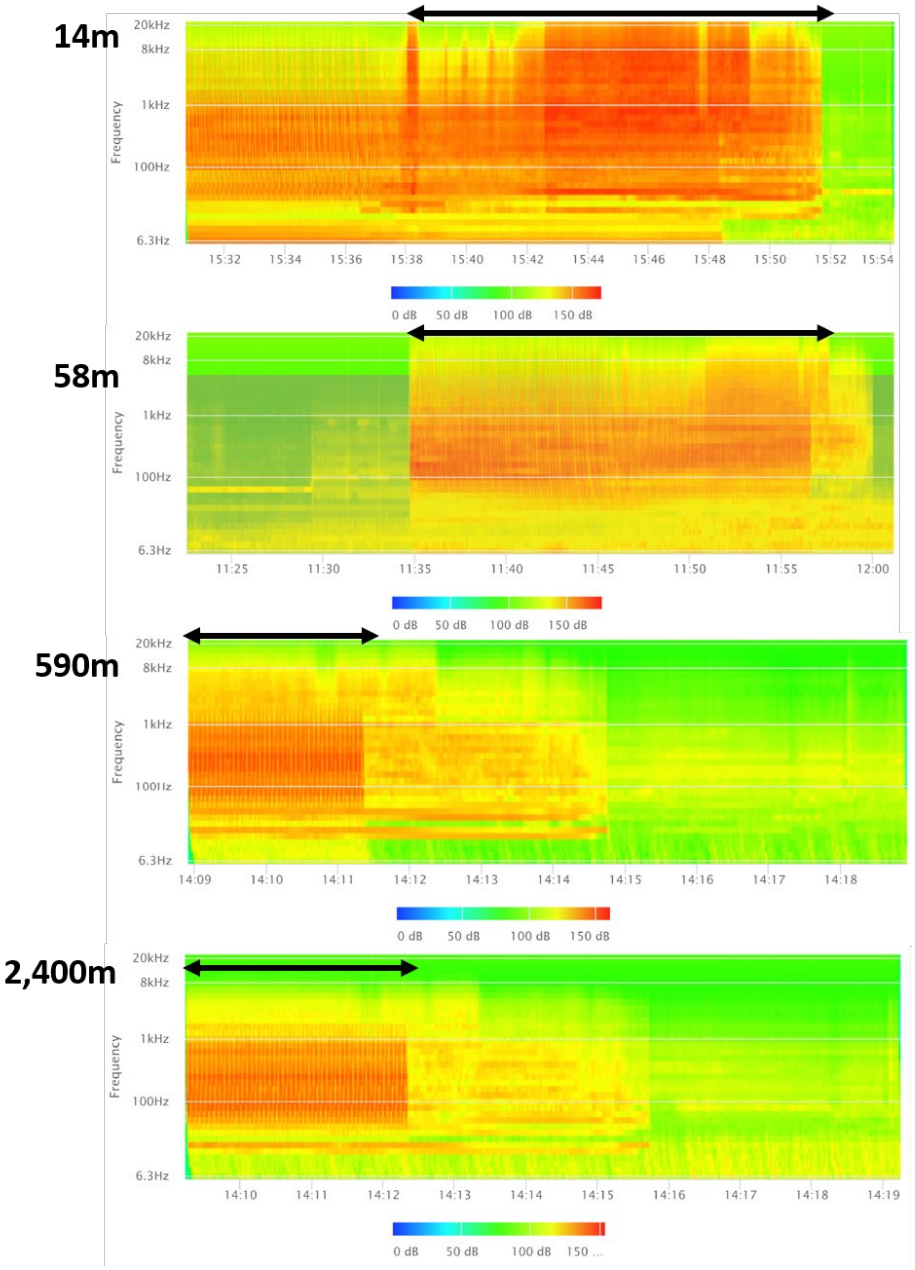

Figure C-7. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-1 on June 10, 2020

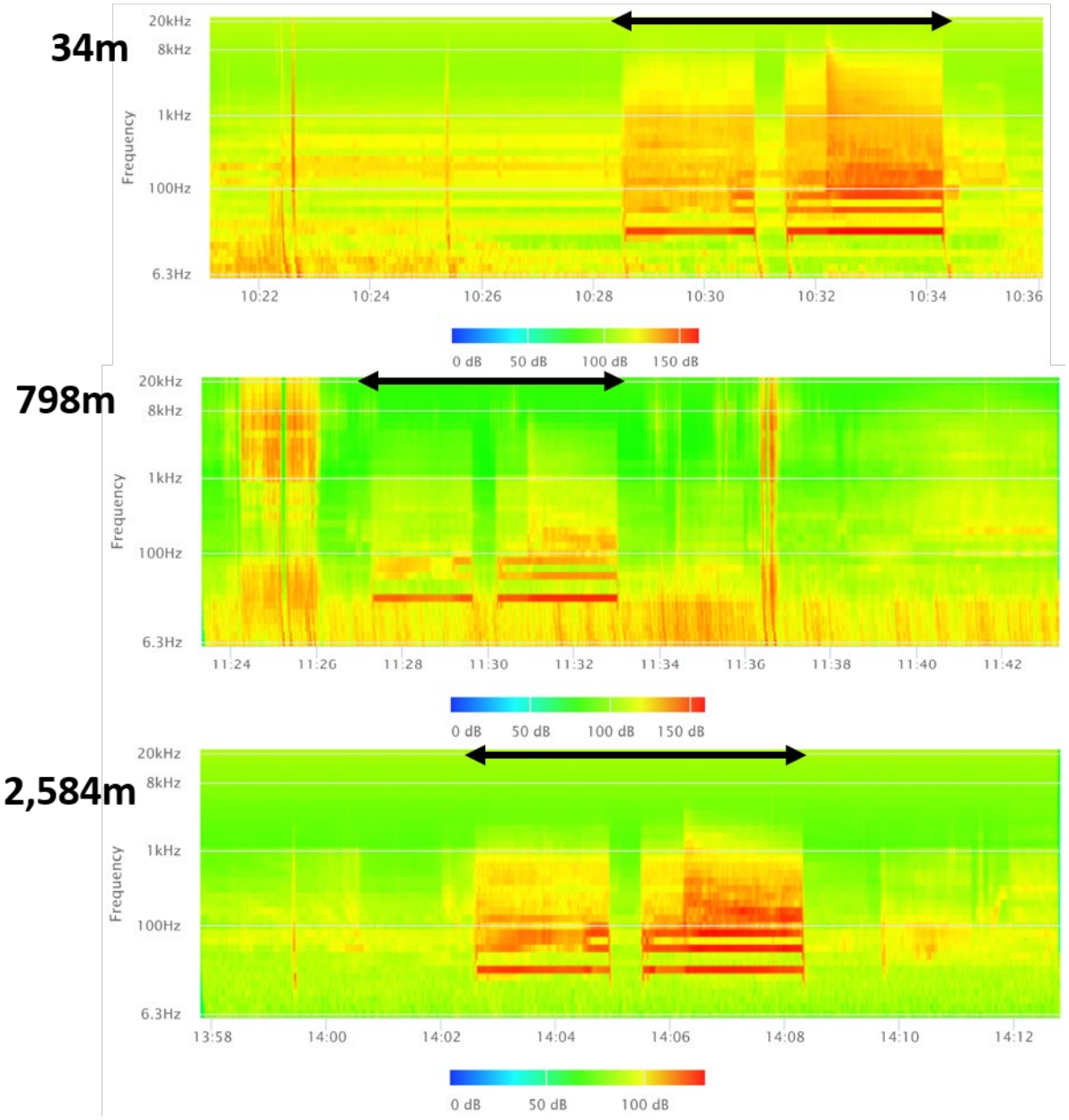

Figure C-8. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile E-1 on June 12, 2020

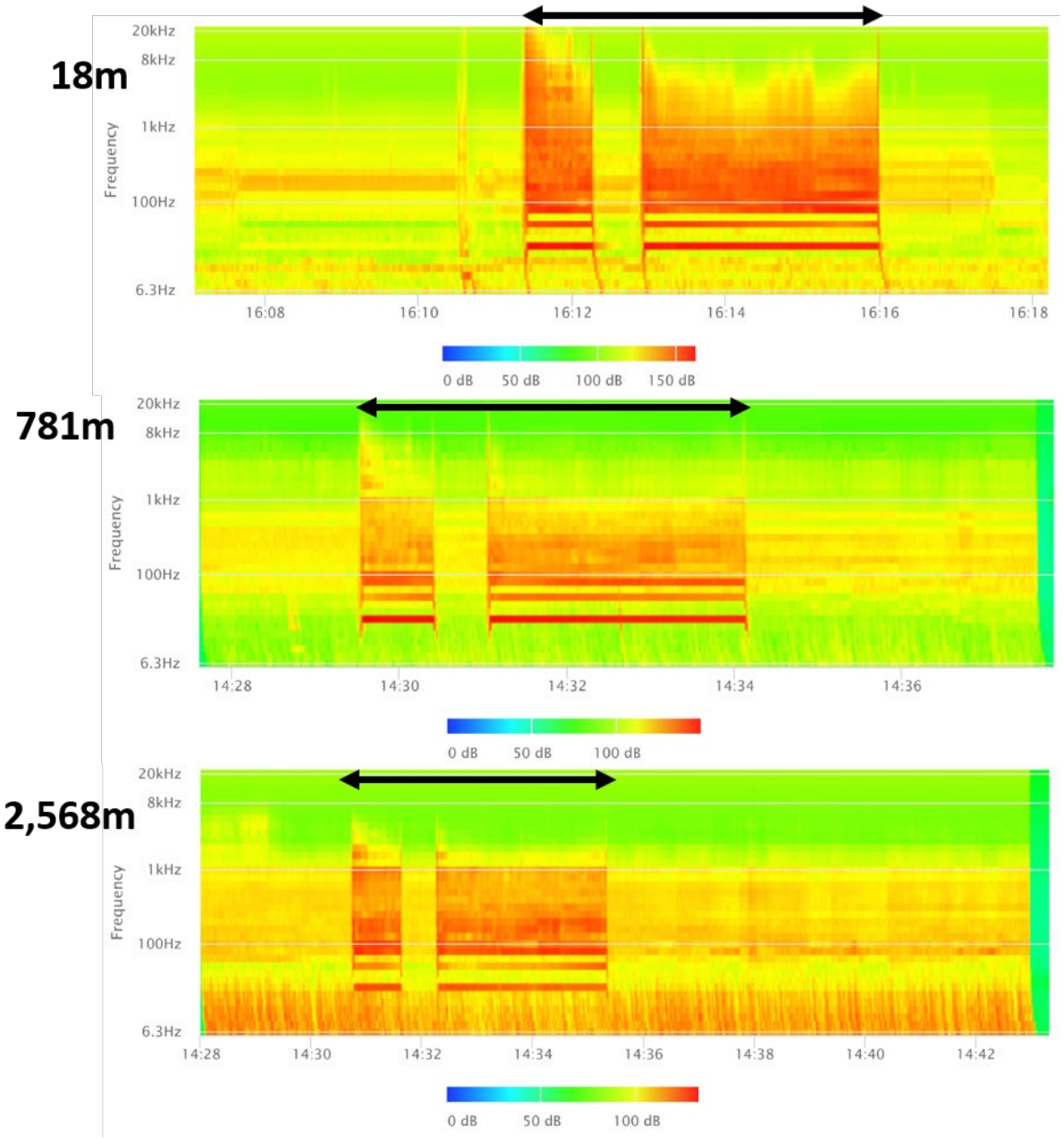

Figure C-9. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile B-2 on June 12, 2020

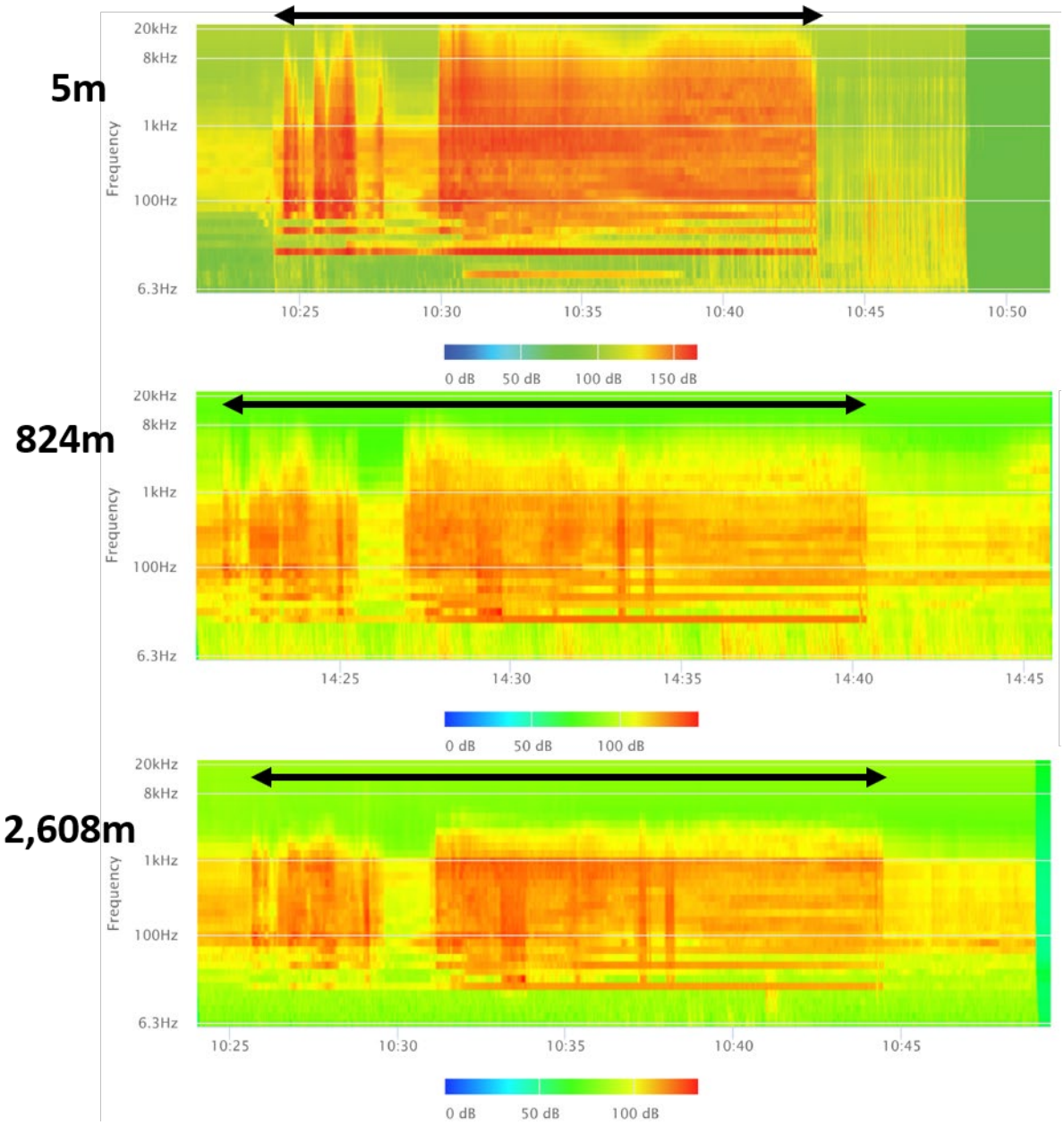

Figure C-10. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile T-13 on June 12, 2020

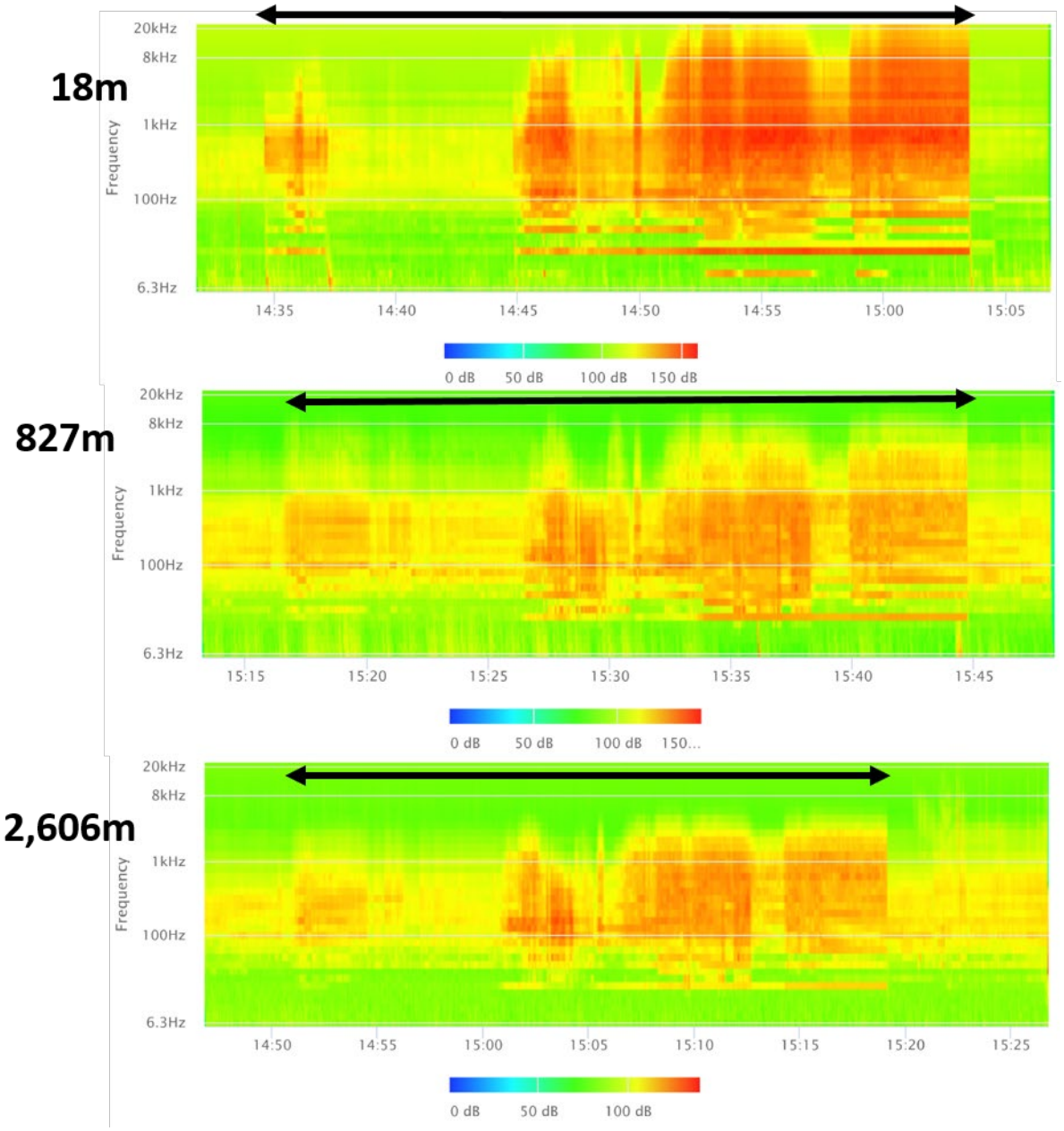

Figure C-11. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile T-14 on June 12, 2020

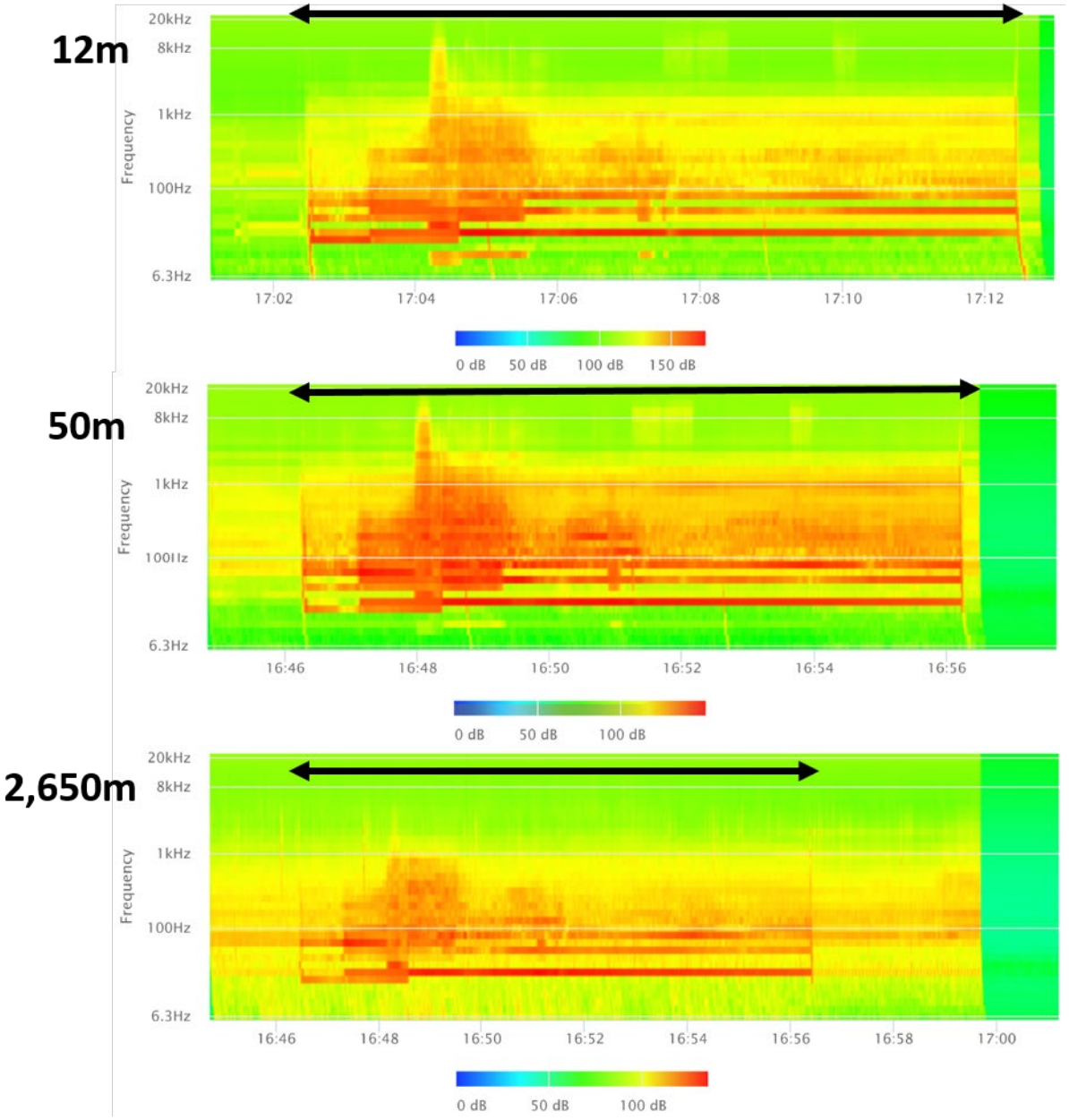

Figure C-12. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile HT-2 on June 14, 2020

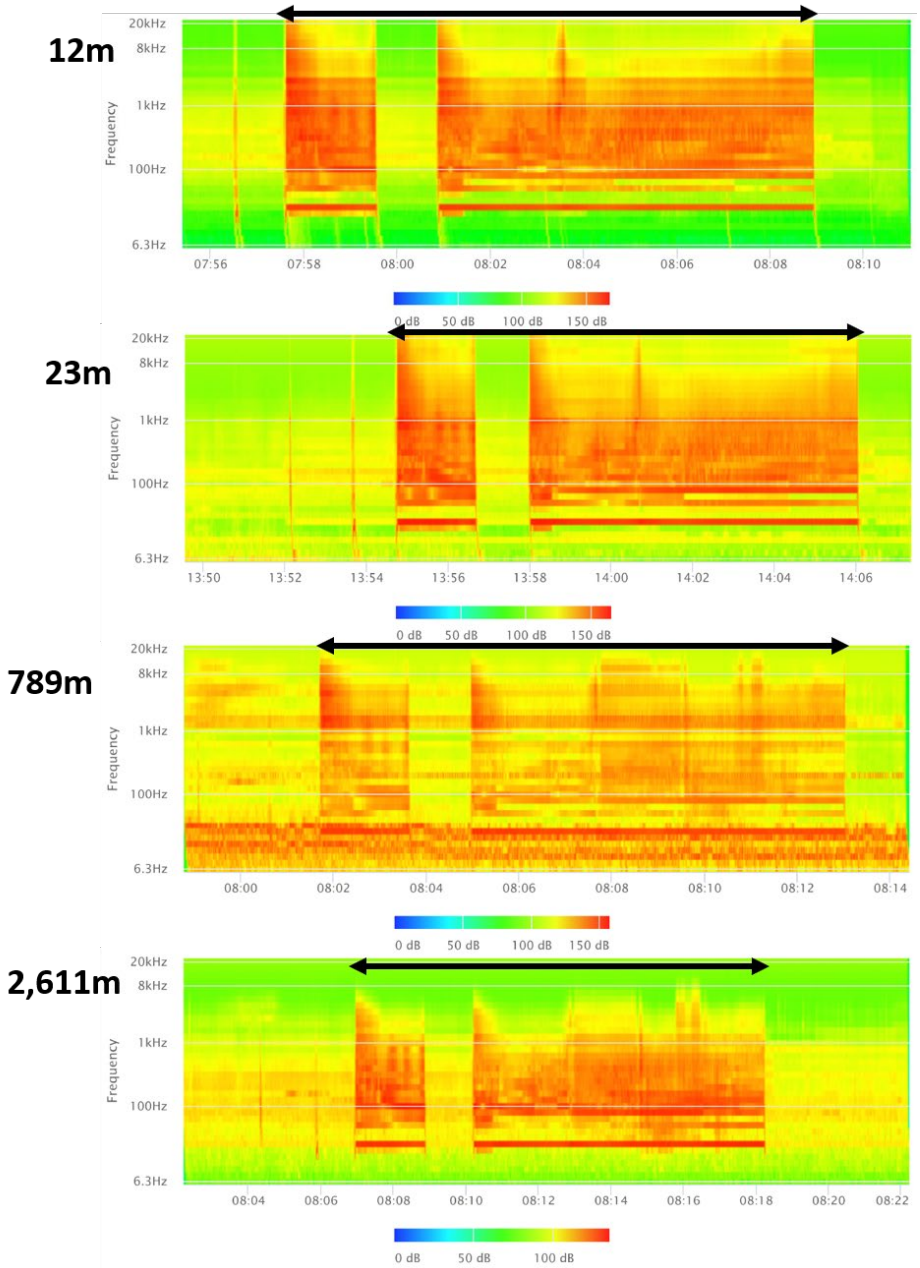

Figure C-13. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile C-2 on June 14, 2020

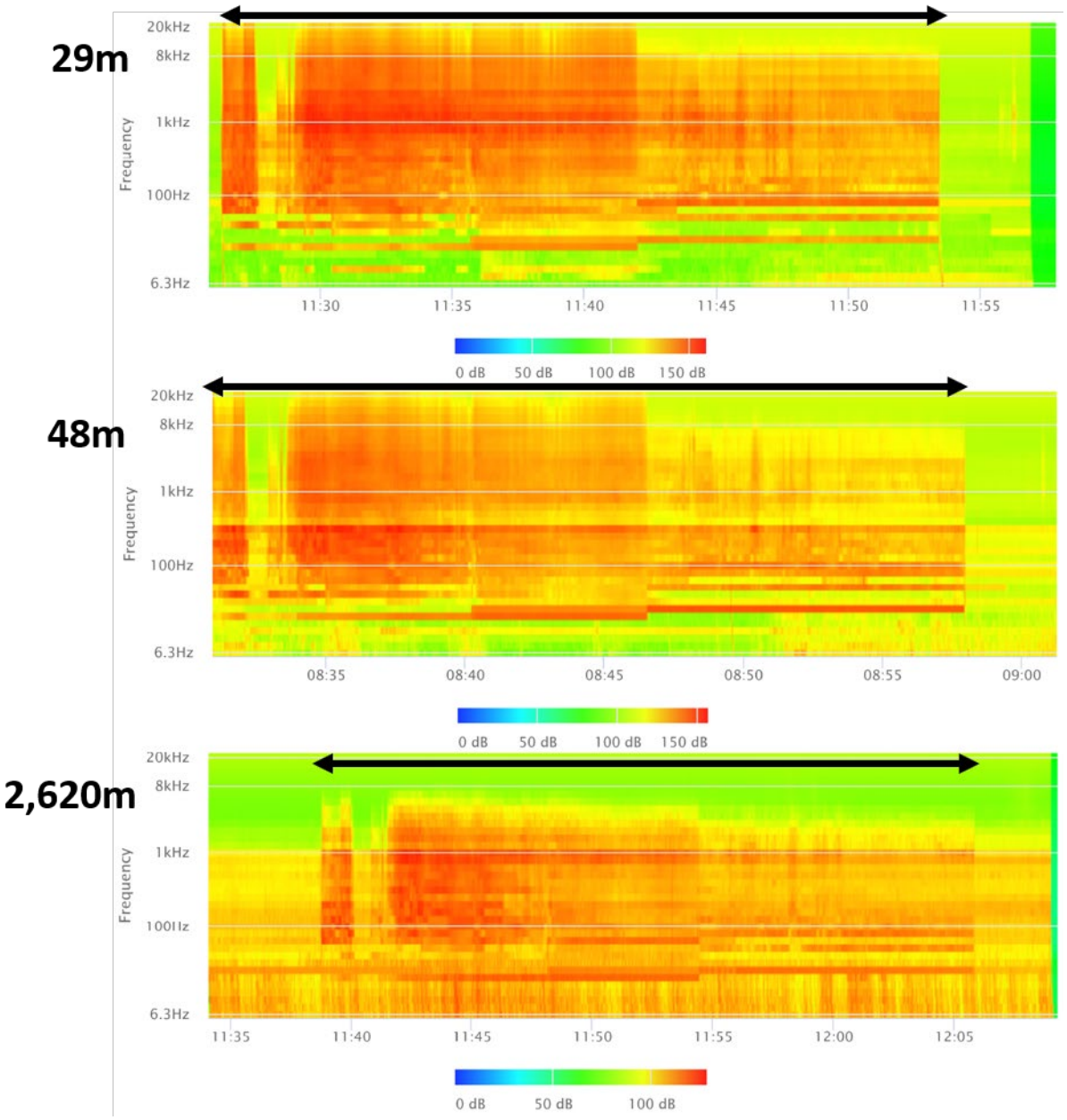

Figure C-14. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile T-15 on June 16, 2020

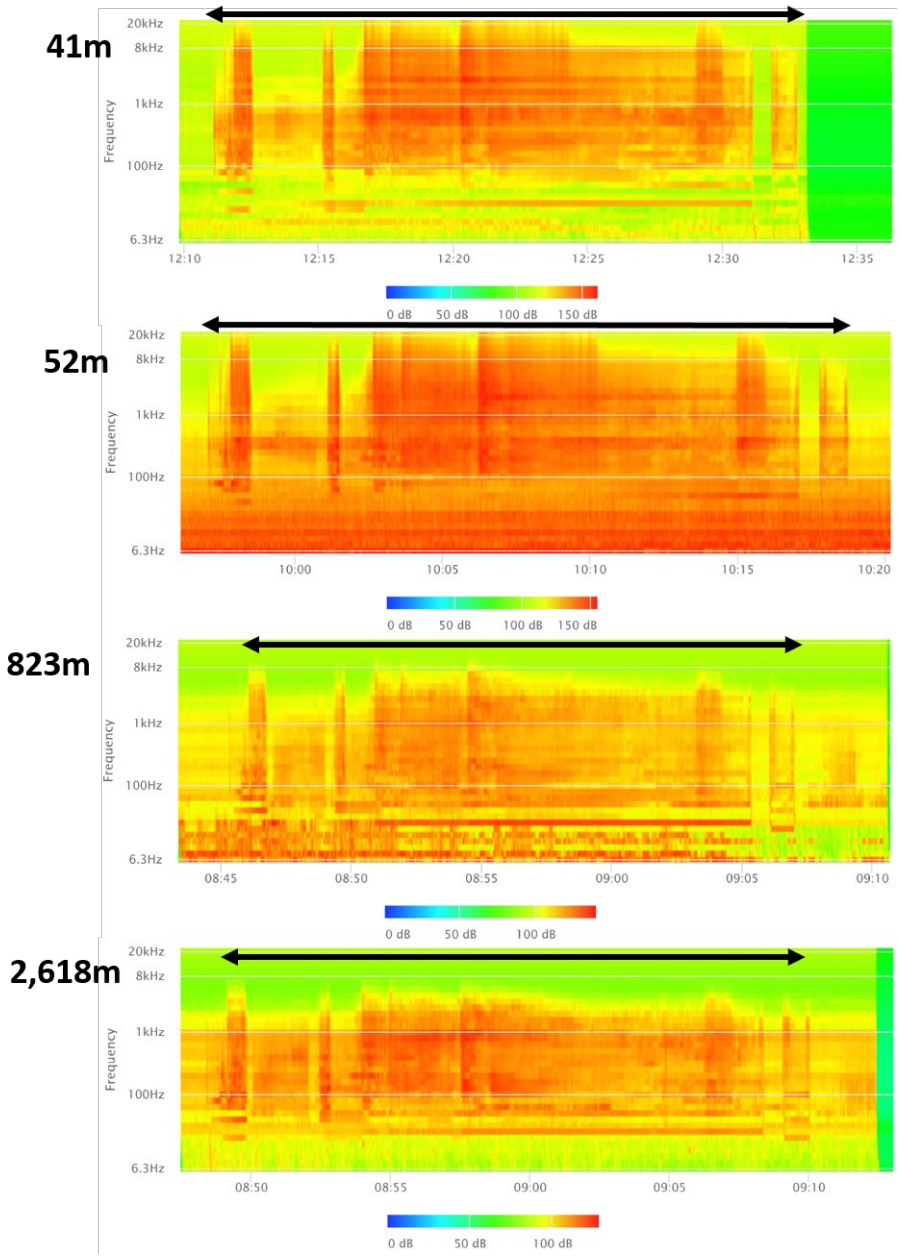

Figure C-15. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile T-16 on June 16, 2020

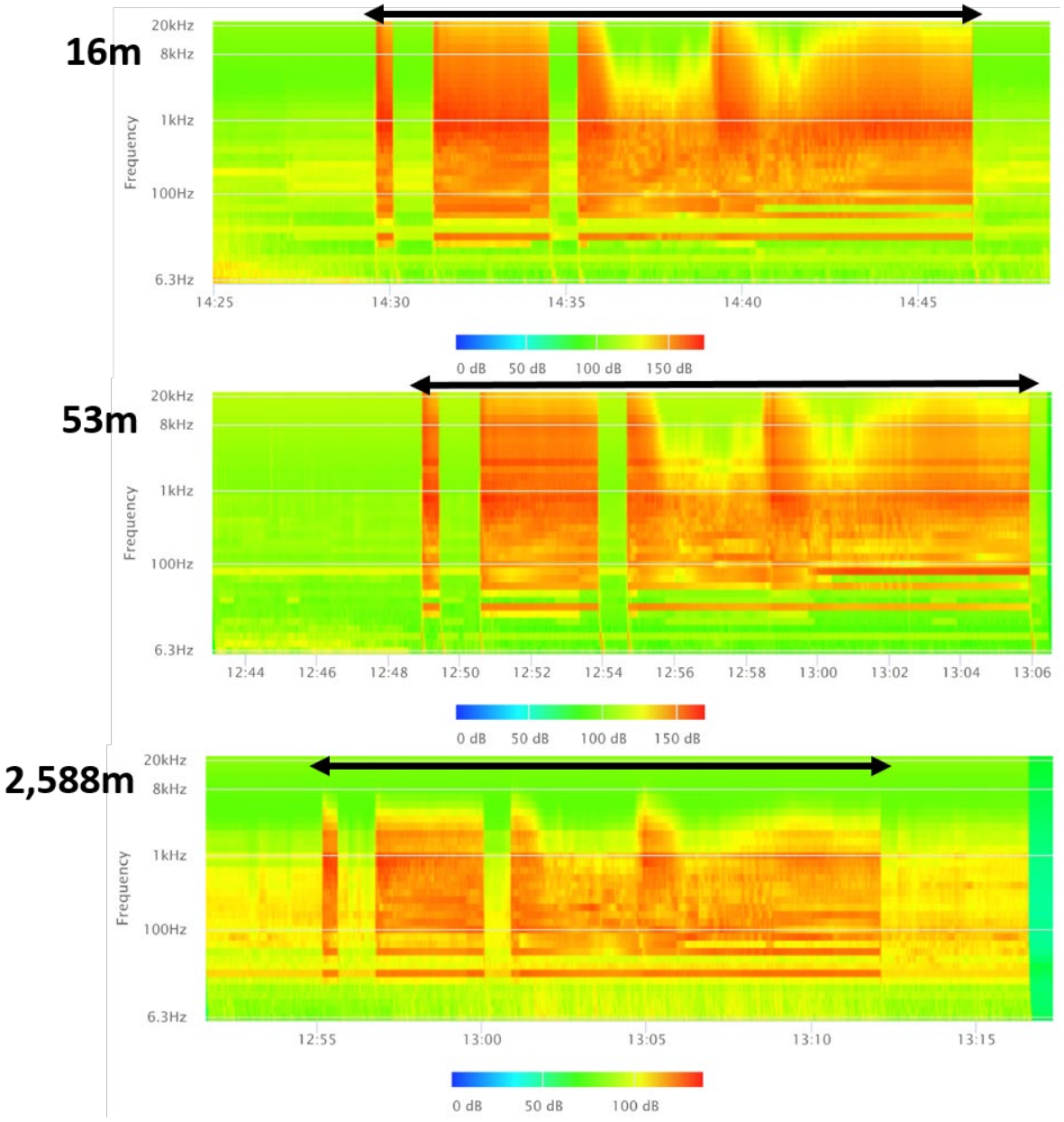

Figure C-16. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile B-1 on June 16, 2020

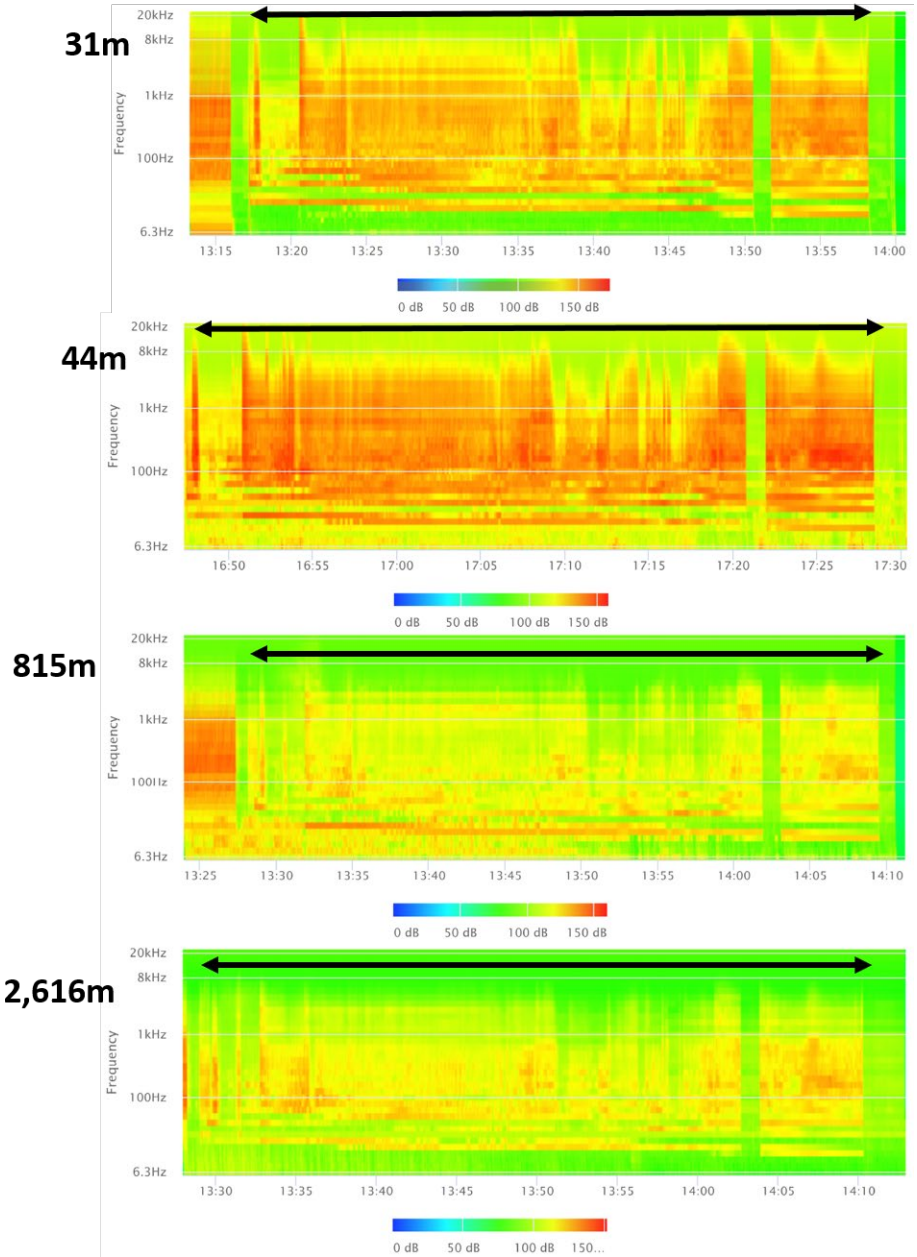

Figure C-17. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-5 on June 16, 2020

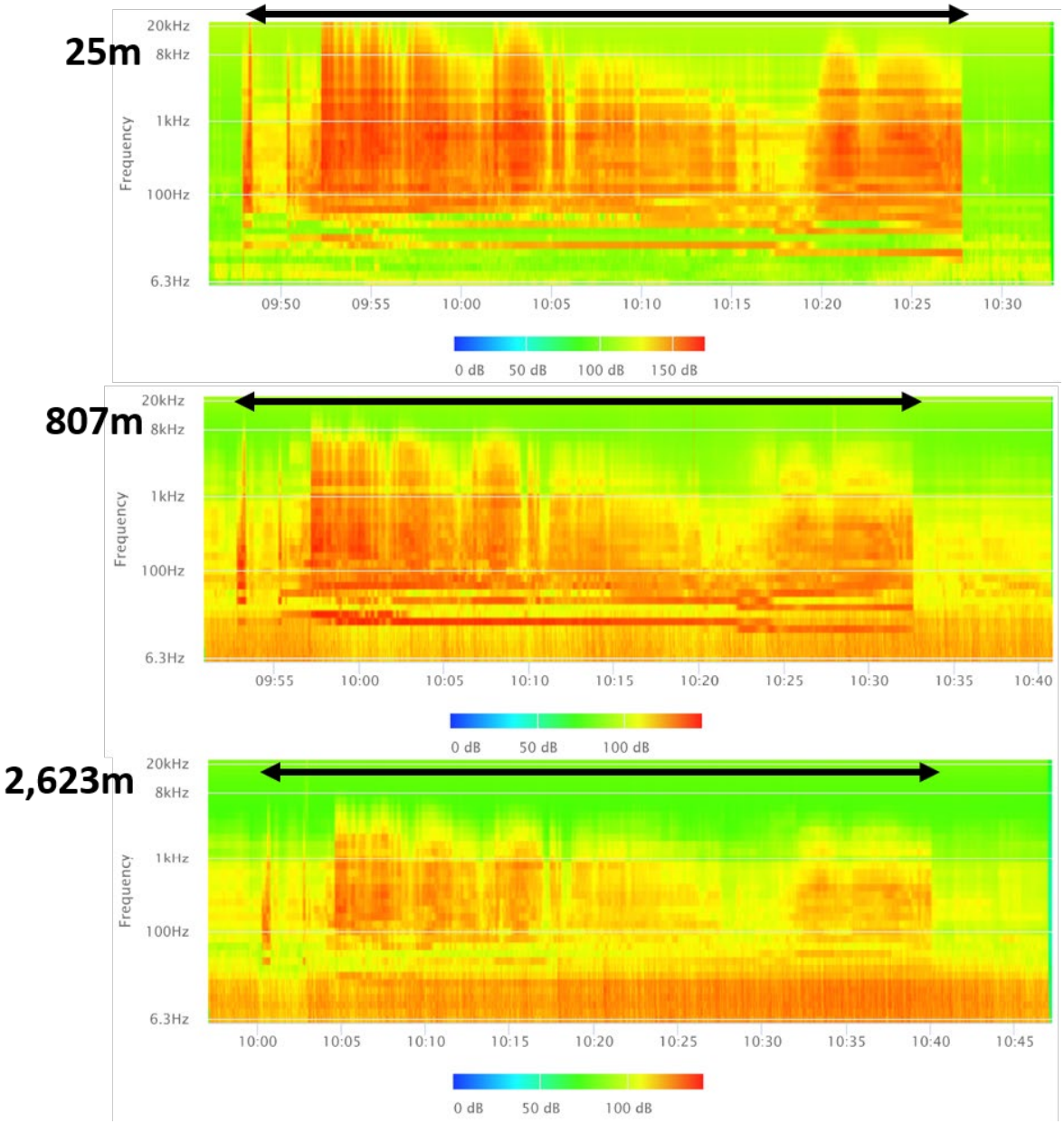

Figure C-18. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-2 on June 17, 2020

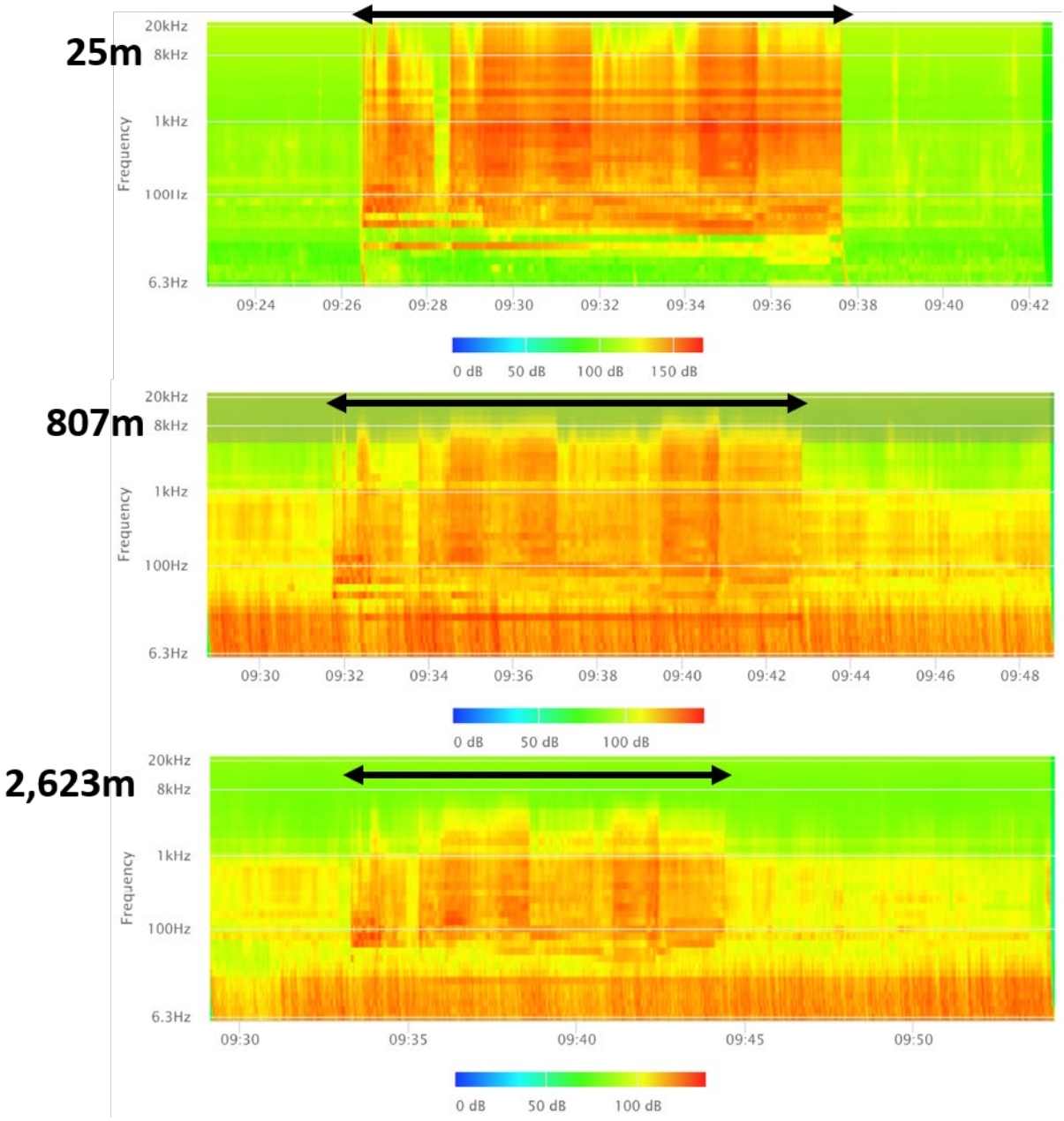

Figure C-19. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-1 on June 17, 2020

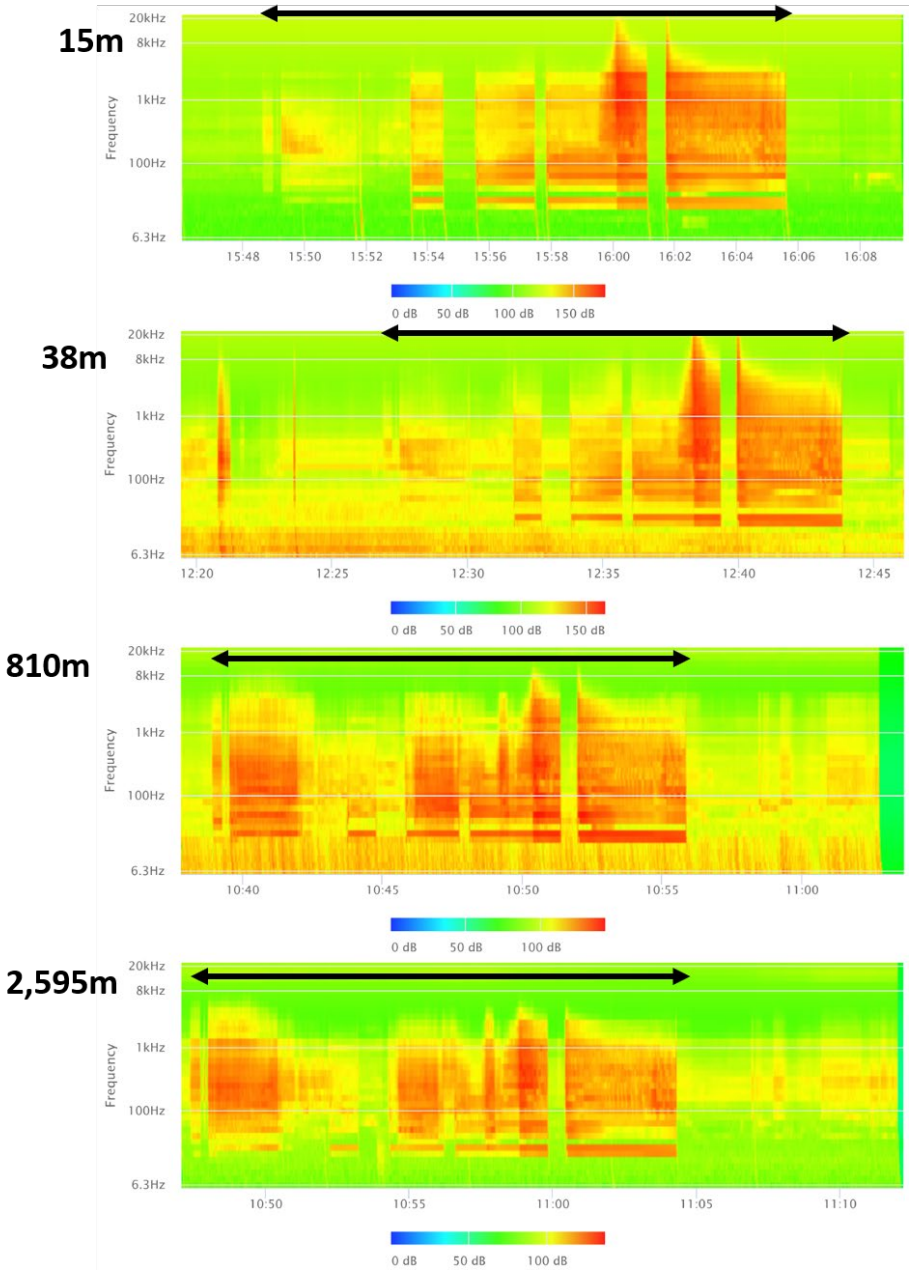

Figure C-20. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile E-4 on June 19, 2020

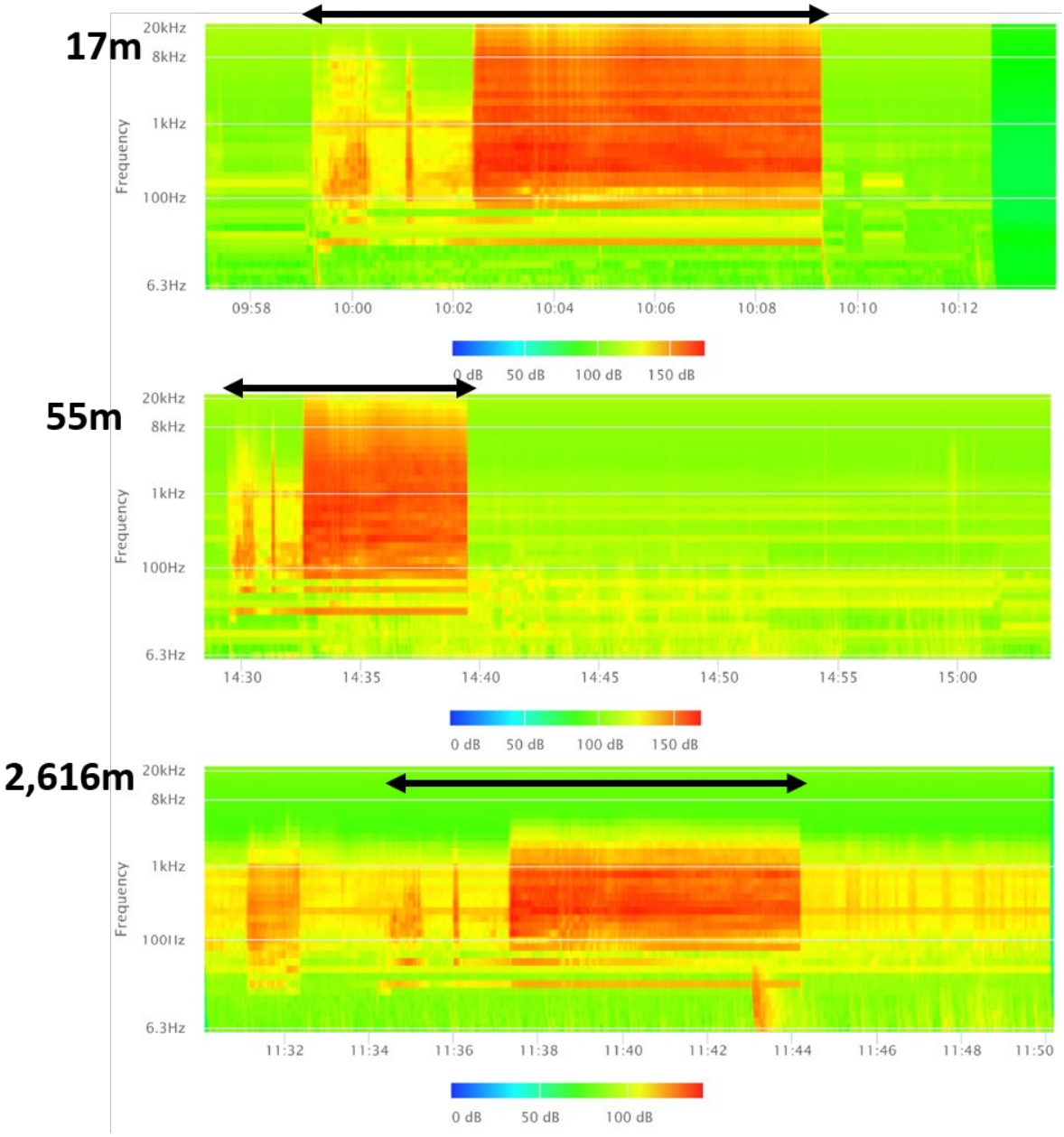

Figure C-21. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile GT-3 on June 20, 2020

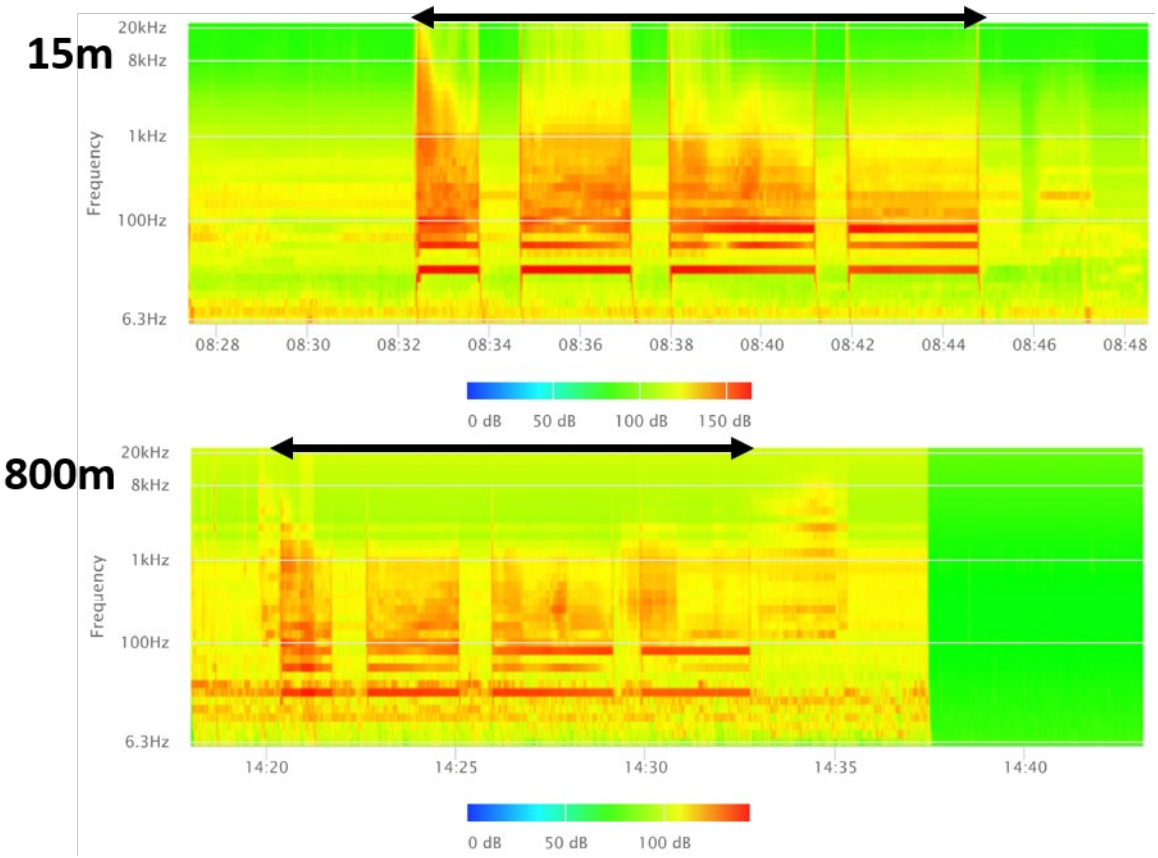

Figure C-22. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile B-5 on June 23, 2020

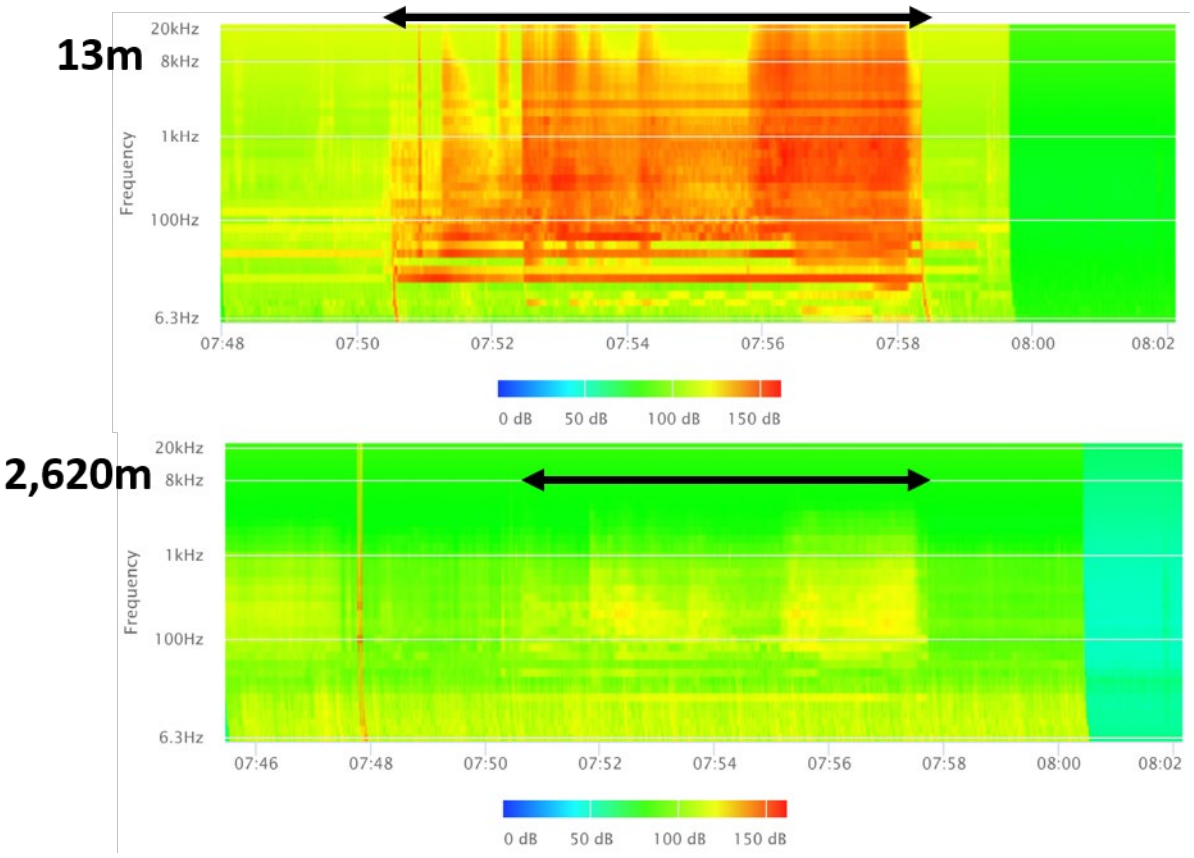

Figure C-23. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-3 on June 24, 2020

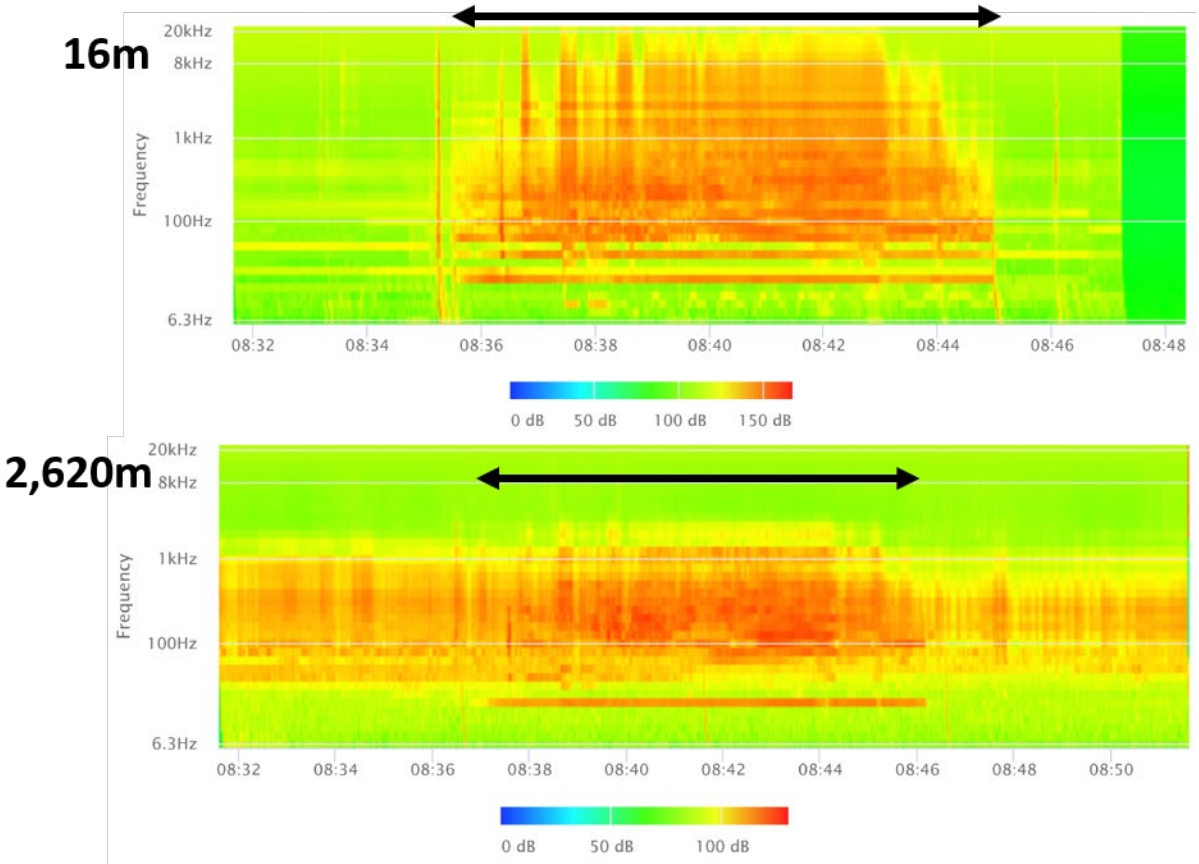

Figure C-24. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-1 on June 24, 2020

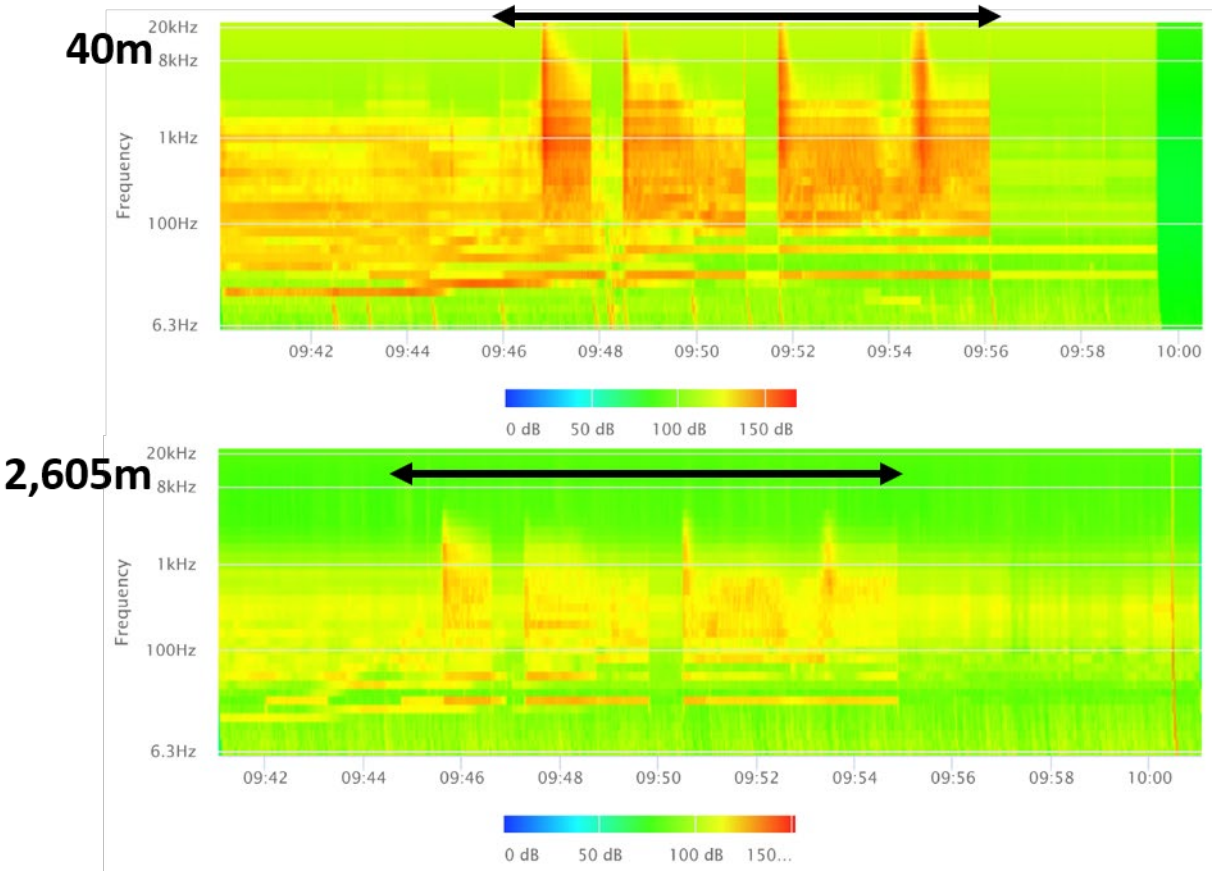

Figure C-25. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile B-4 on June 24, 2020

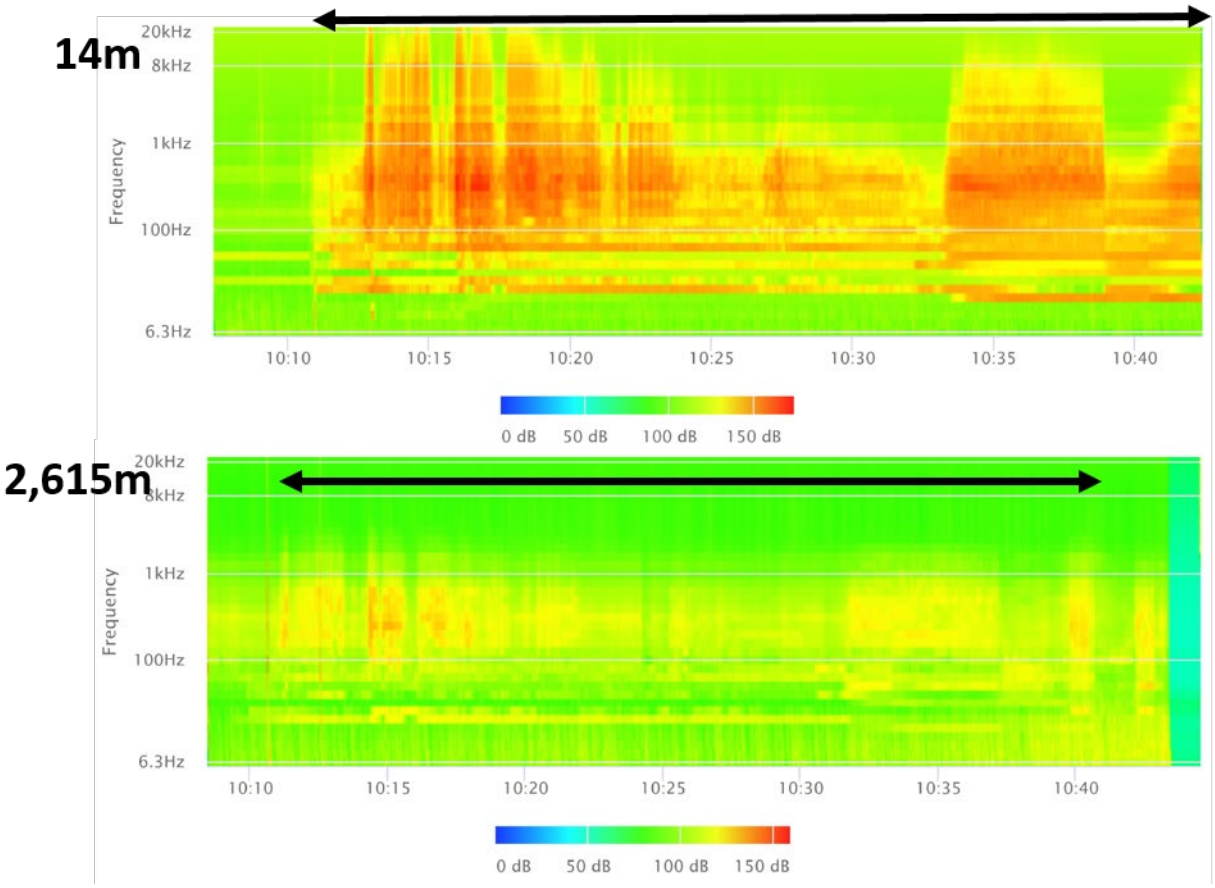

Figure C-26. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-5 on June 24, 2020

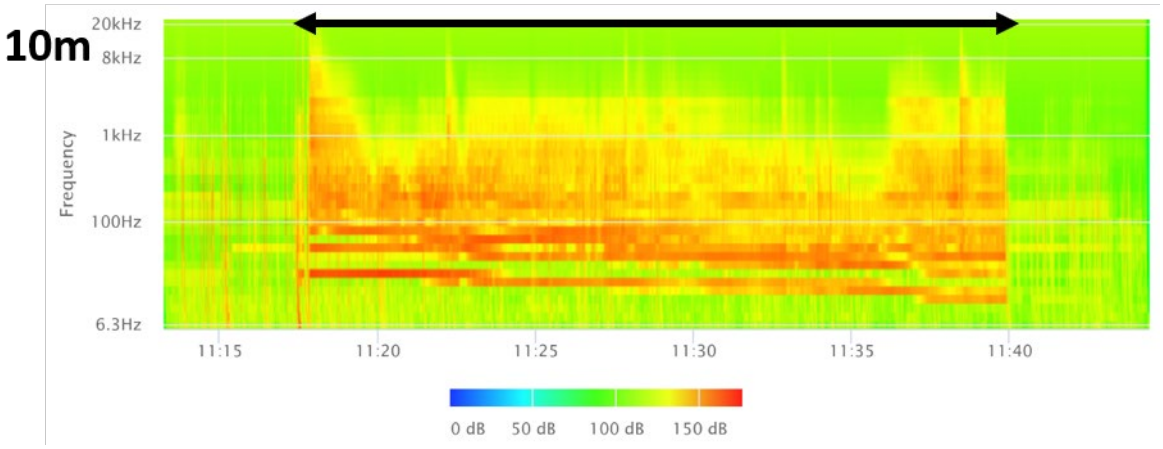

Figure C-27. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of Pile S-2 on June 25, 2020

Summary of Spectrograms for Each Air Bubble Casing During Vibratory Driving

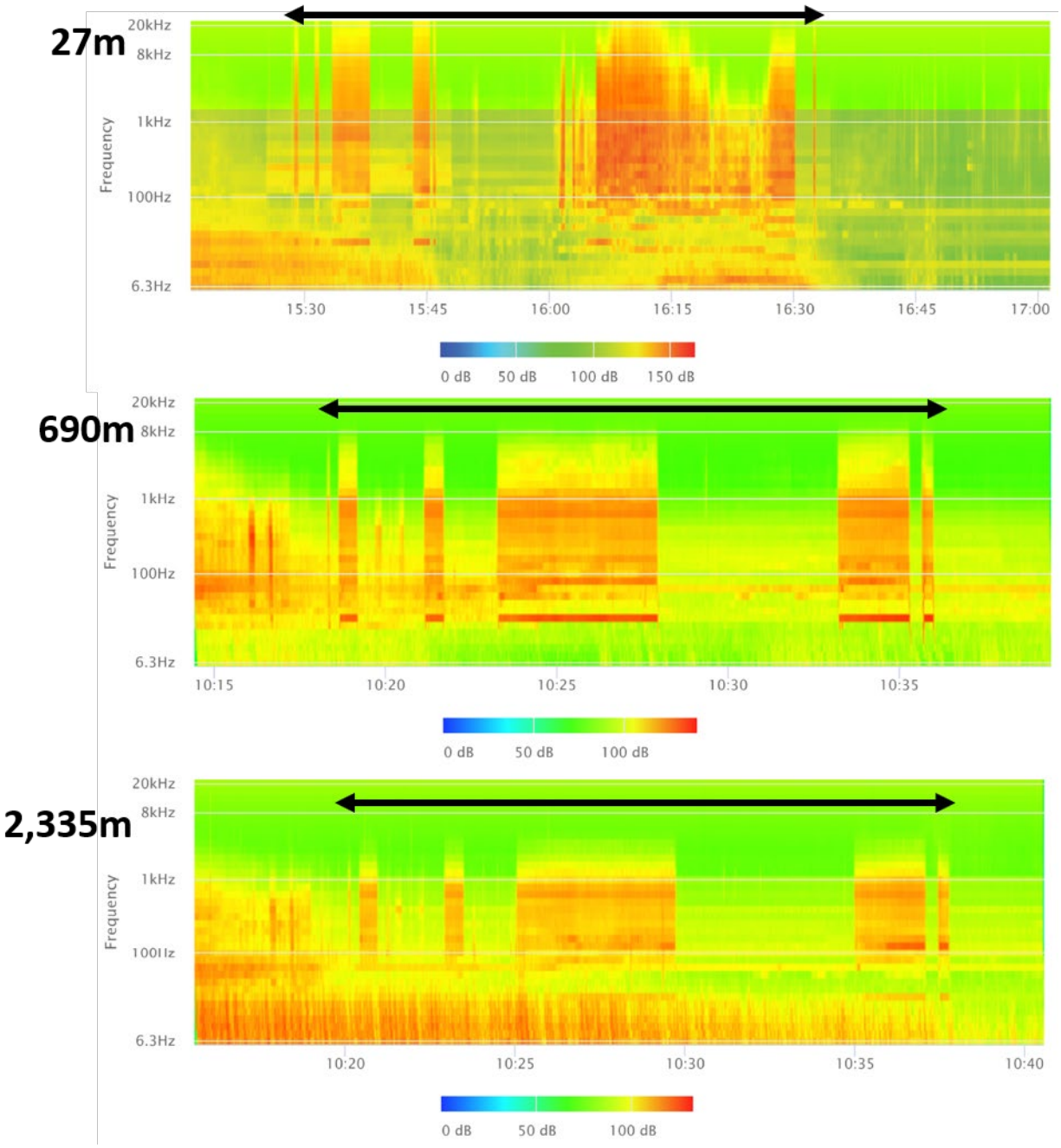

Figure C-28. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of D-1 Air Bubble Casing on June 9, 2020

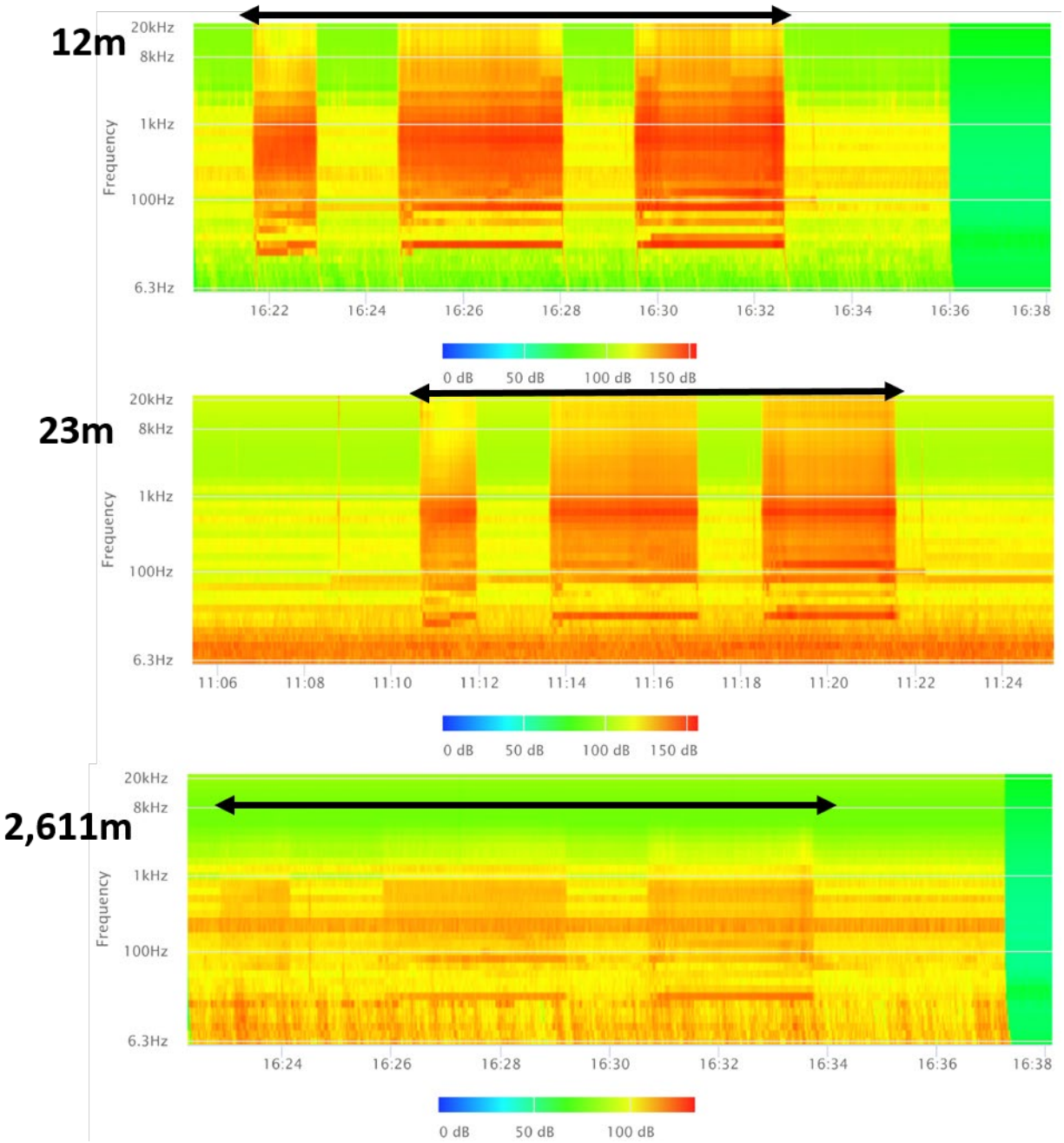

Figure C-29. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of C-2 Air Bubble Casing on June 14, 2020

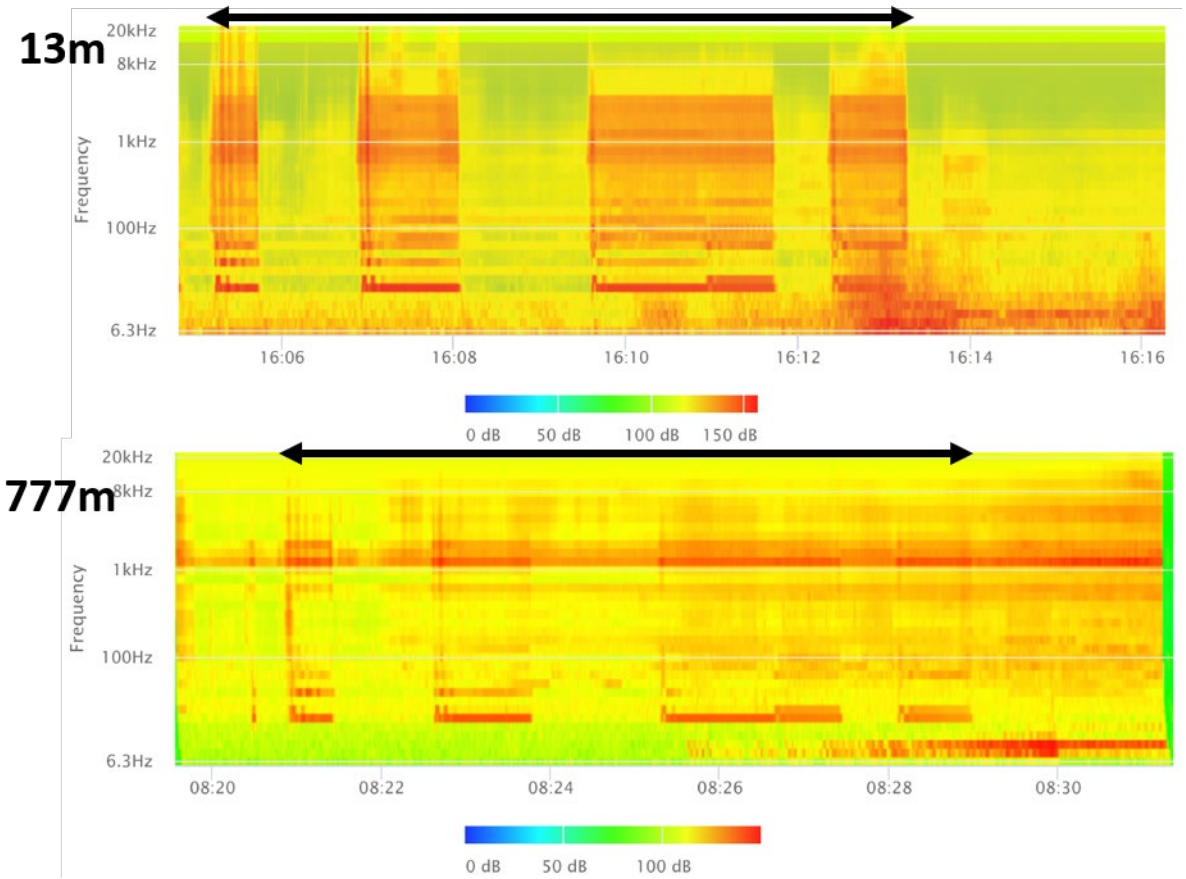

Figure C-30. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of A-2 Air Bubble Casing on June 14, 2020

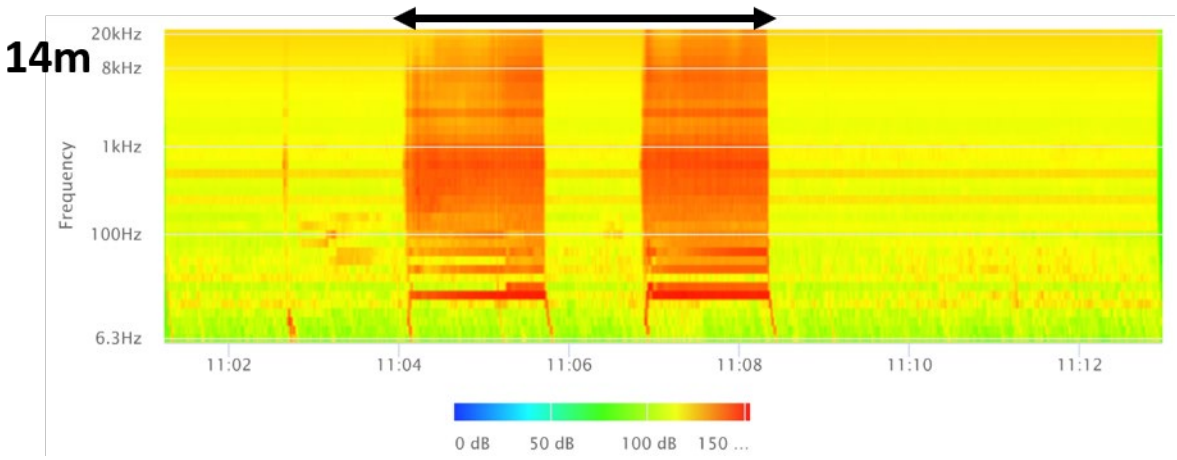

Figure C-31. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of D-5 Air Bubble Casing on June 20, 2020

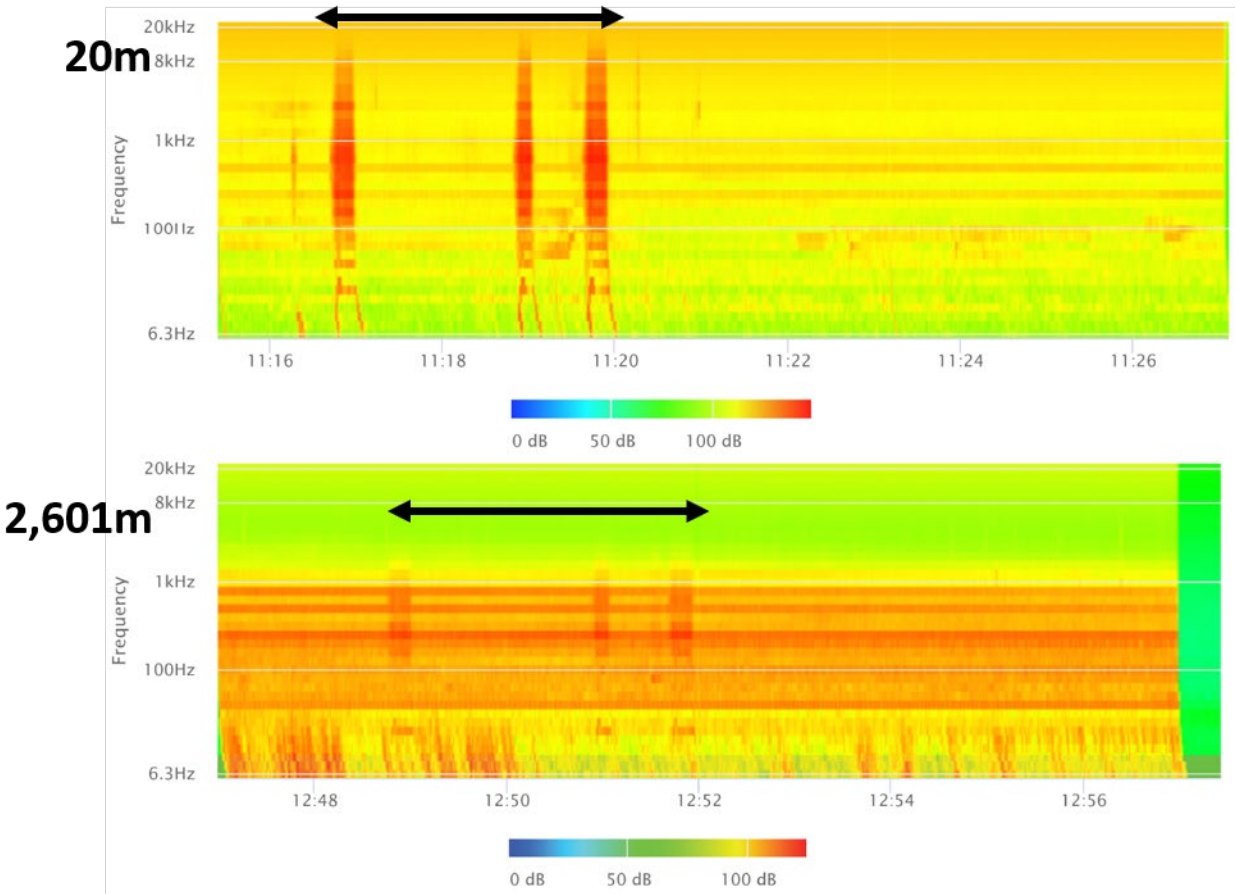

Figure C-32. Spectrogram plots for each measurement location in the westward direction during the vibratory driving of E-5 Air Bubble Casing on June 20, 2020

Summary of Spectrograms for the Pin Pile Removal

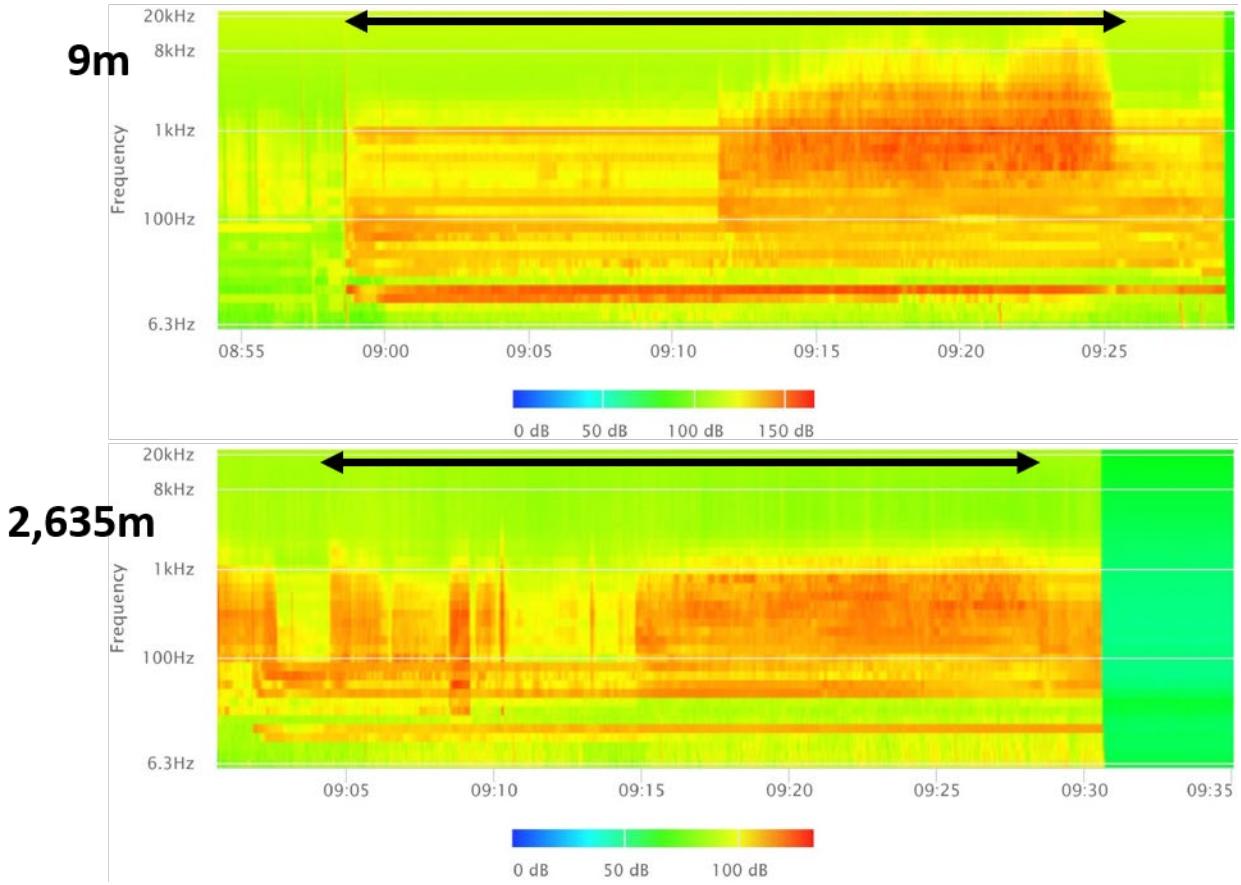

Figure C-33. Spectrogram plots for each measurement location in the westward direction during the vibratory removal of the Pin Pile on June 24, 2020

Summary of Spectrograms for Each 48-inch Pile During Impact Driving

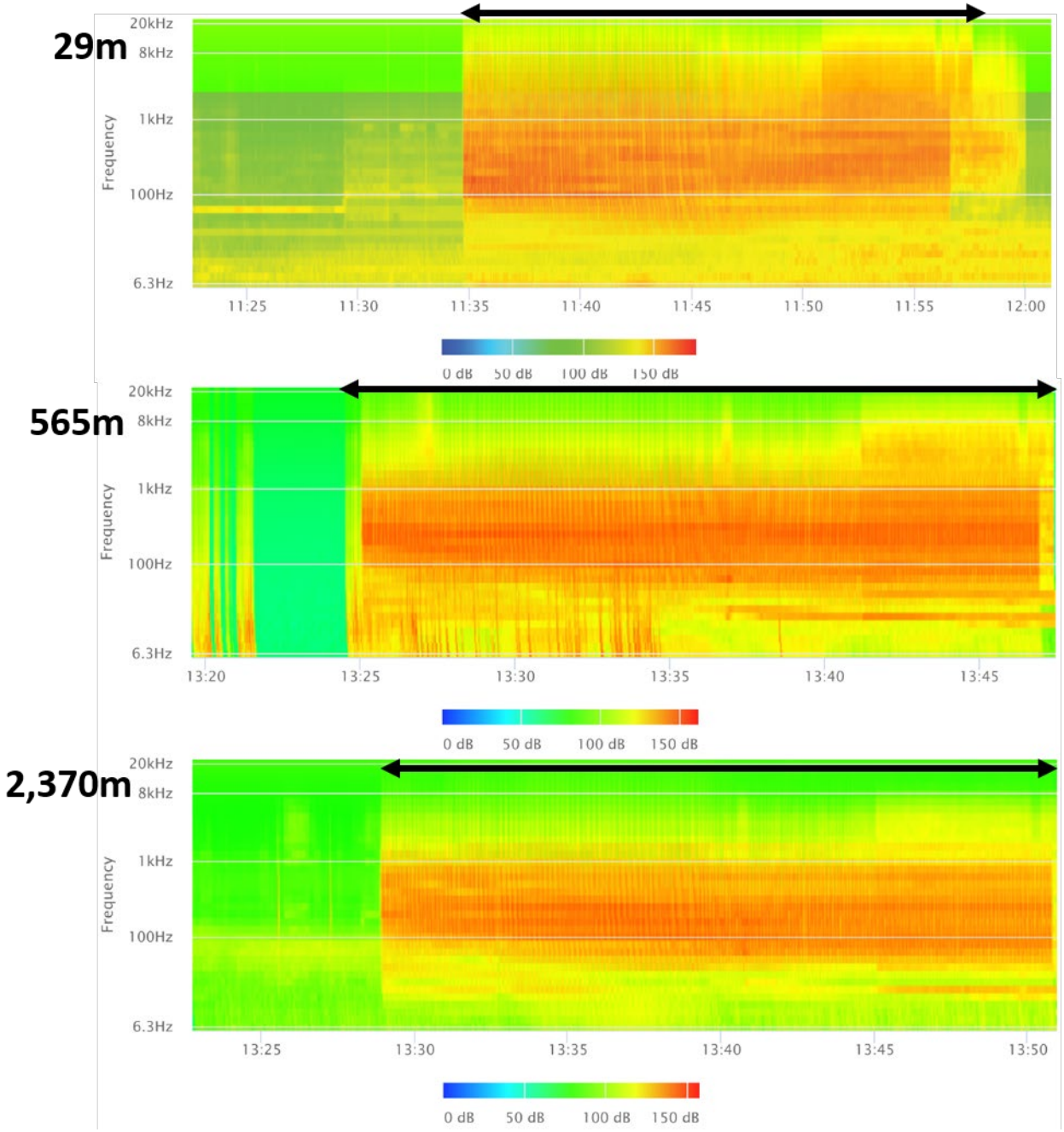

Figure C-34. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile D-1 on June 10, 2020

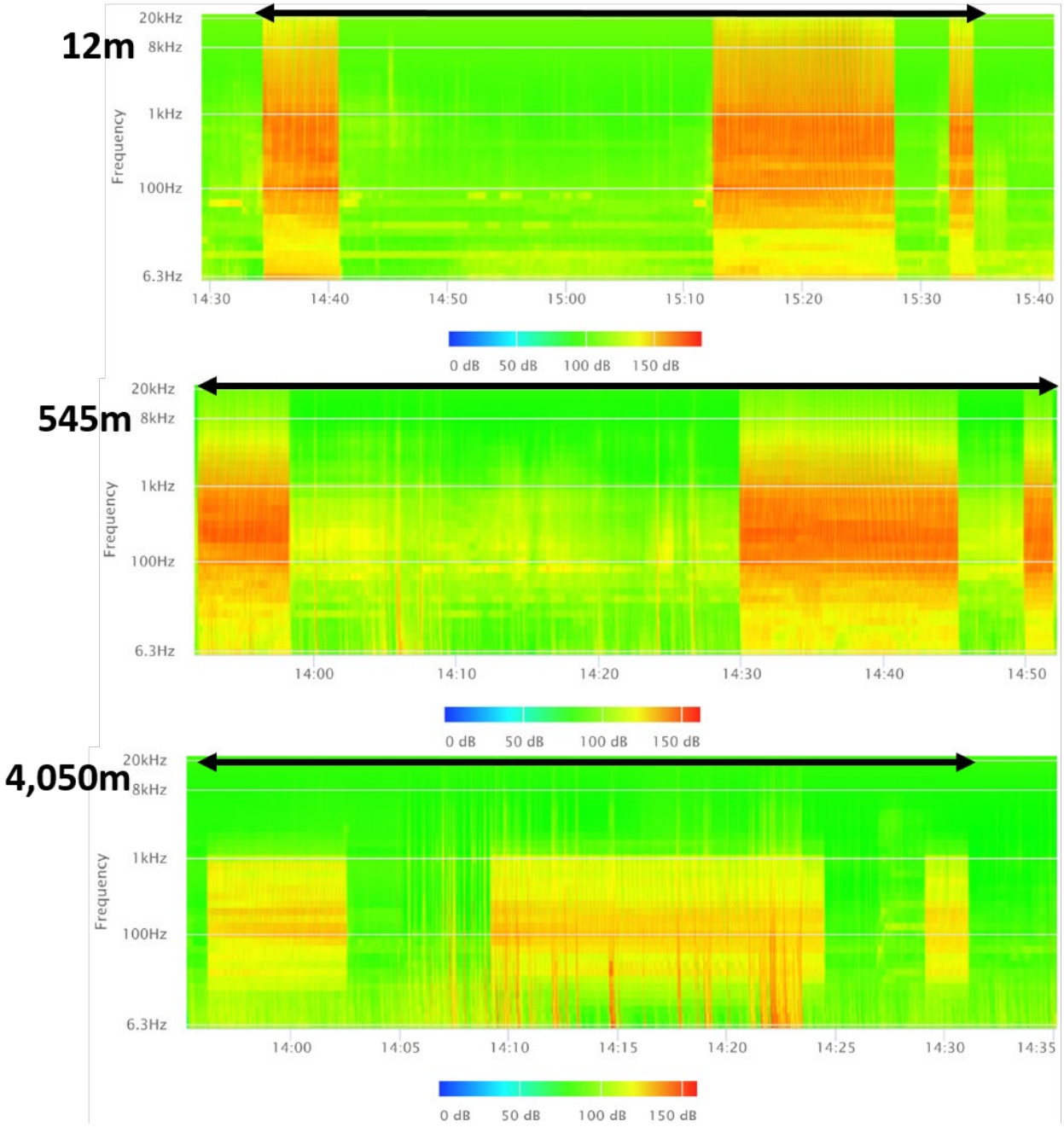

Figure C-35. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile A-1 on June 10, 2020

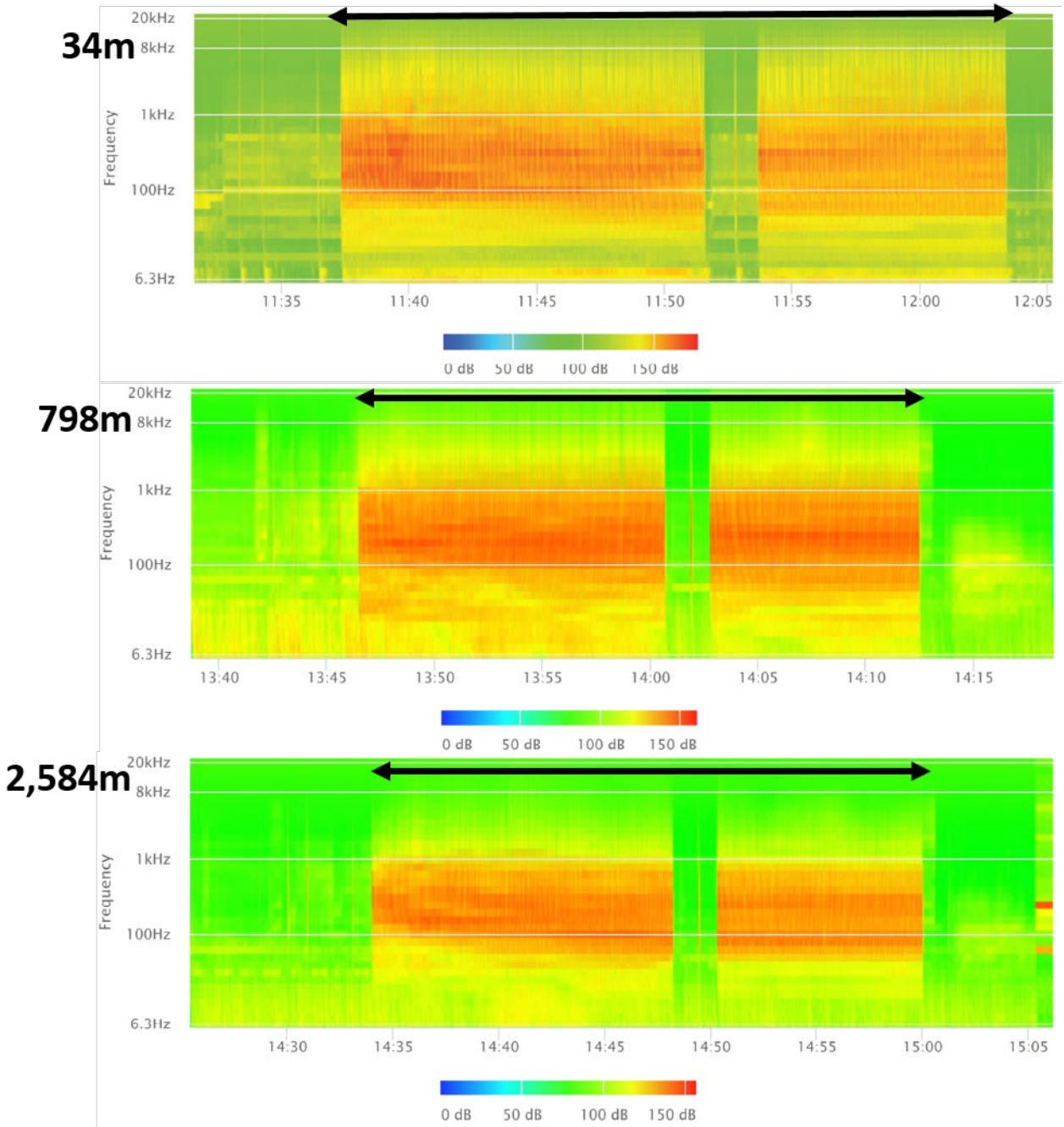

Figure C-36. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile E-1 on June 12, 2020

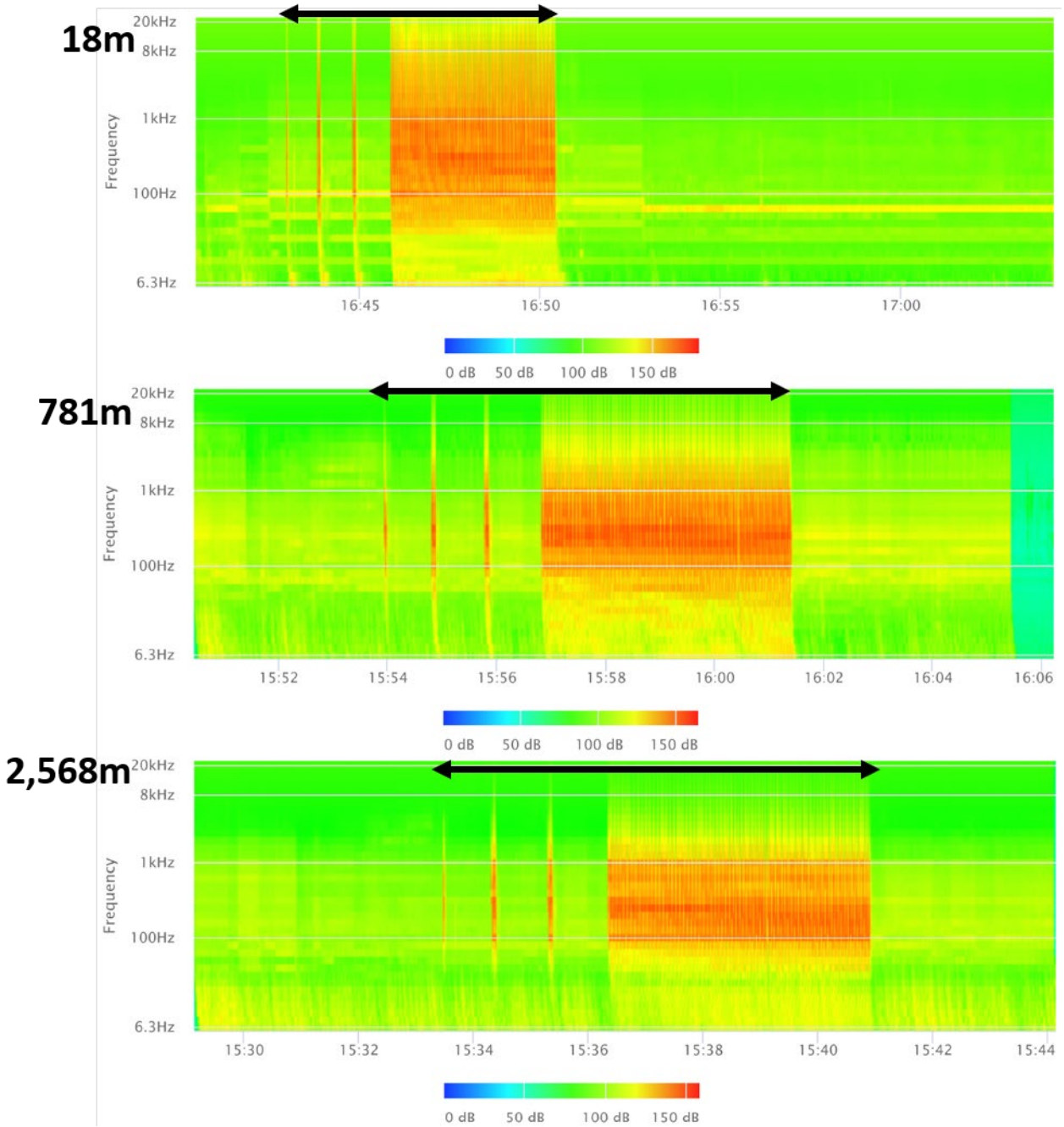

Figure C-37. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile B-2 on June 12, 2020

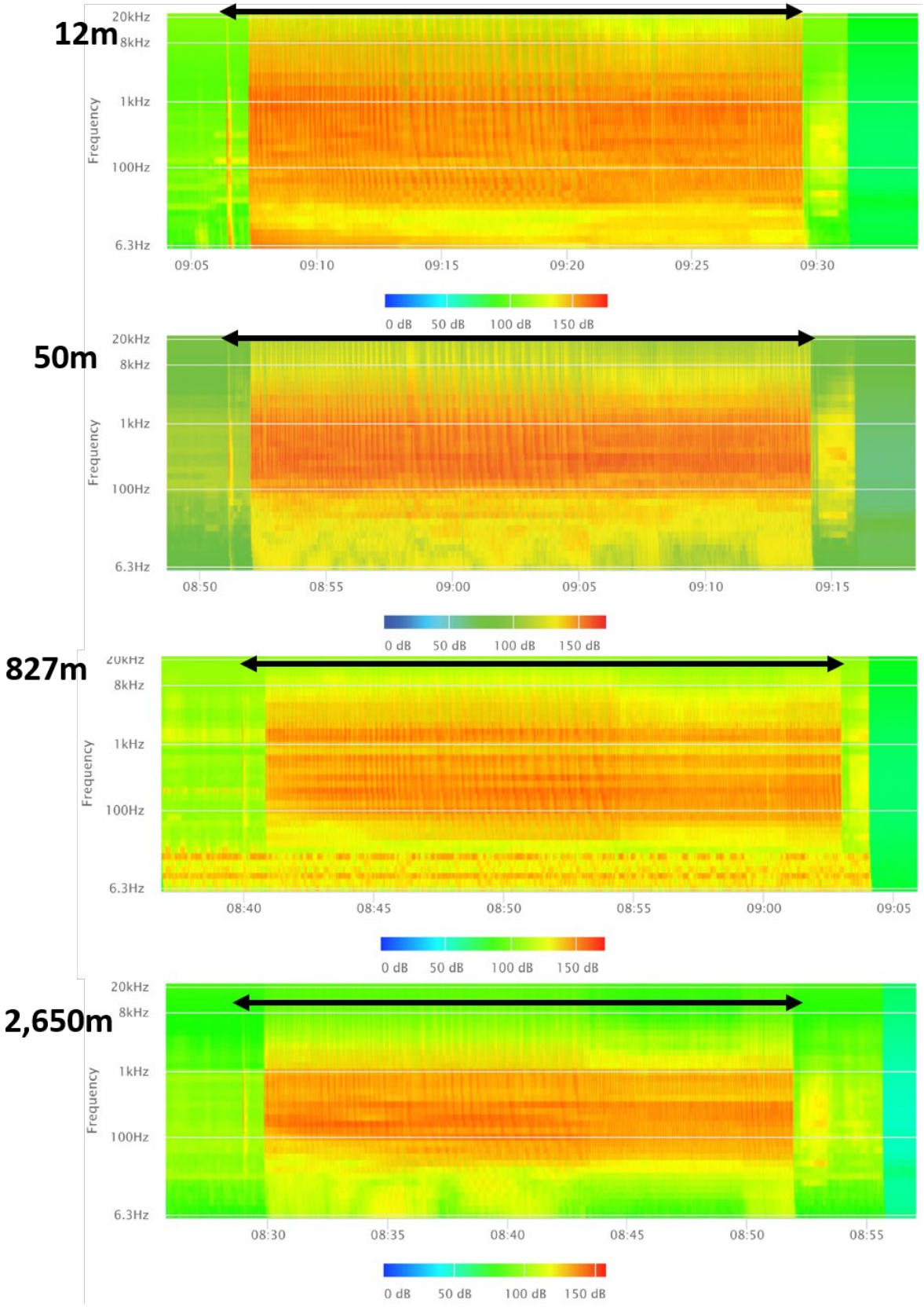

Figure C-38. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile HT-2 on June 14, 2020

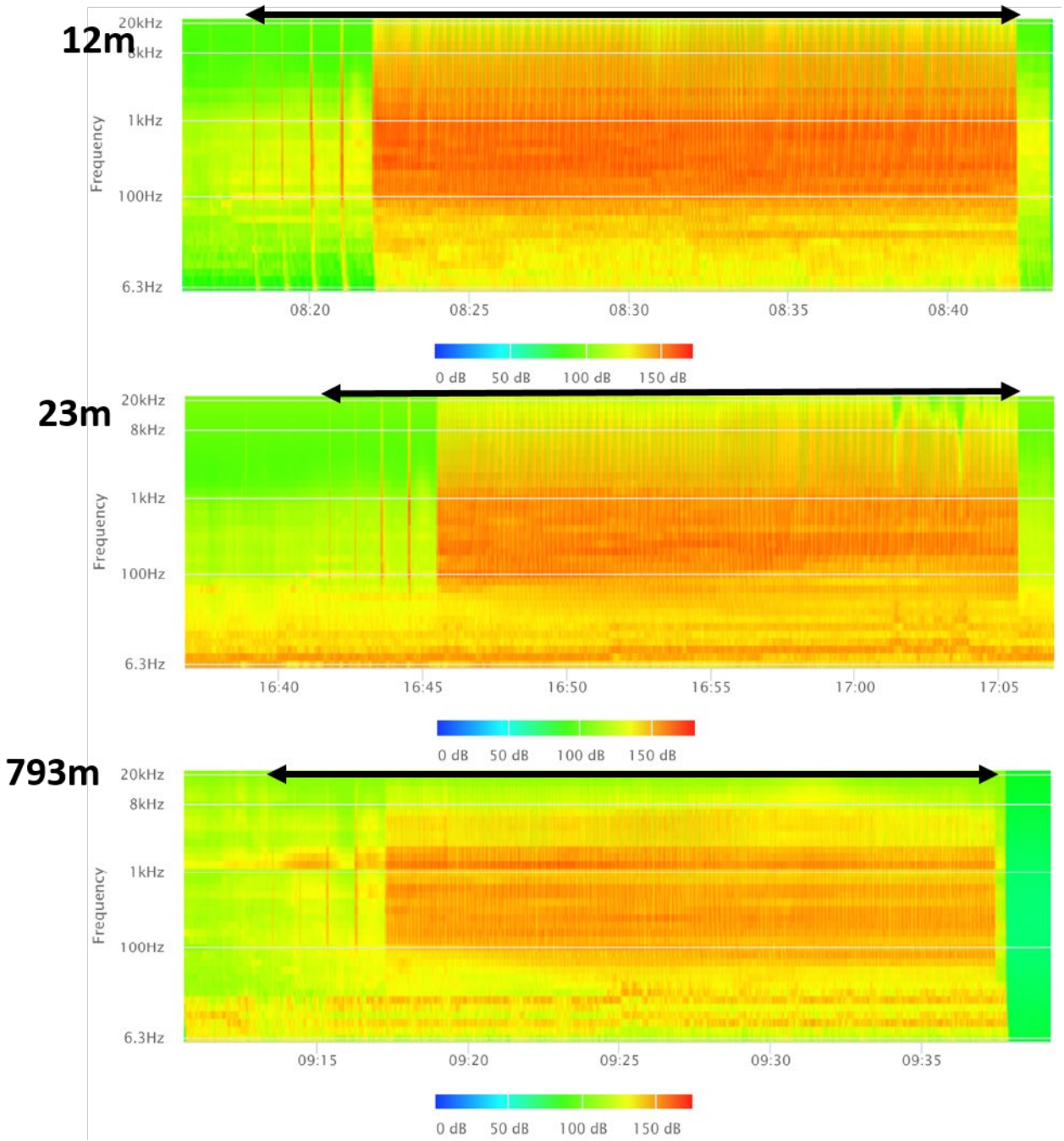

Figure C-39. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile C-2 on June 14, 2020

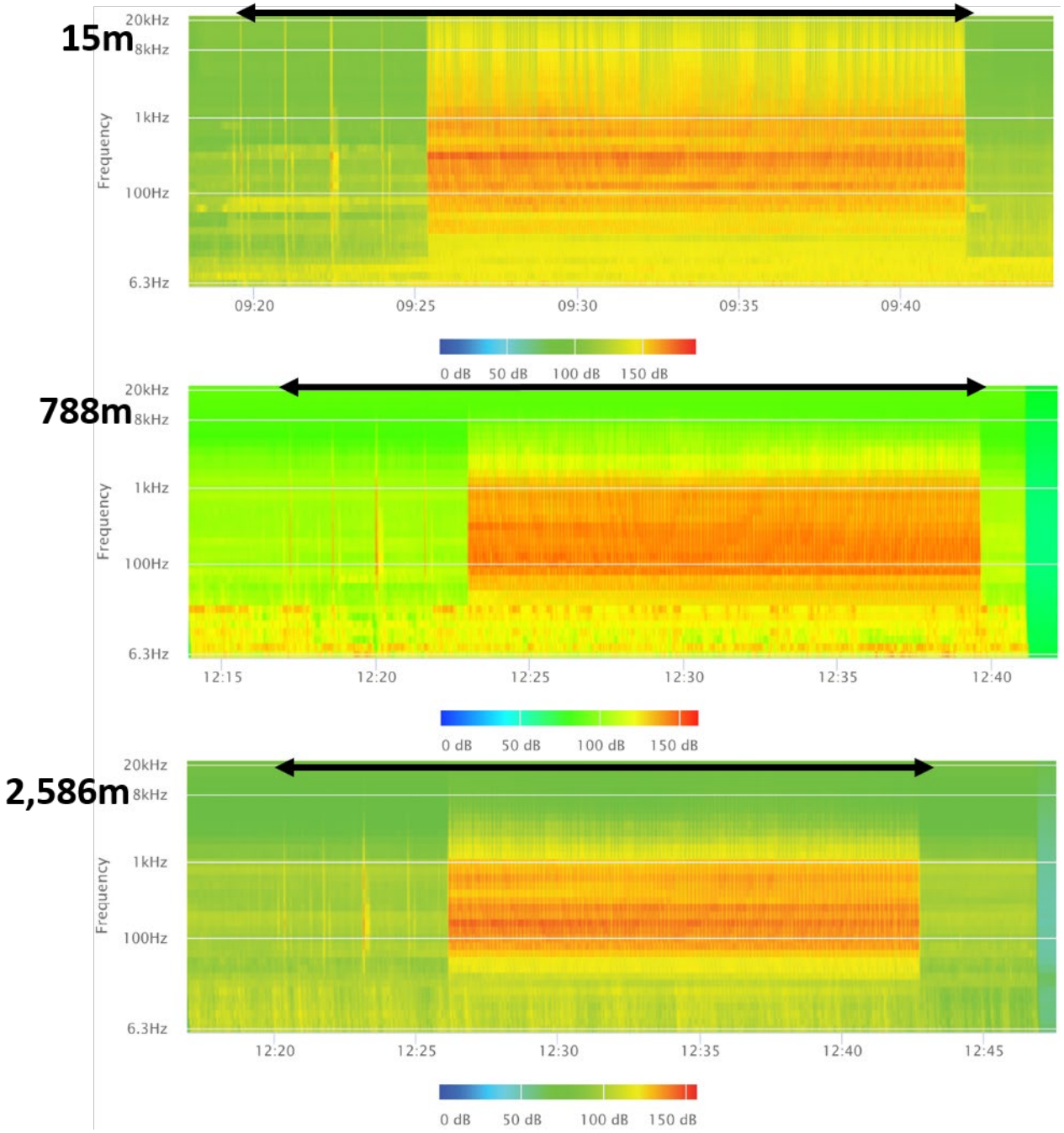

Figure C-40. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile B-2 on June 16, 2020

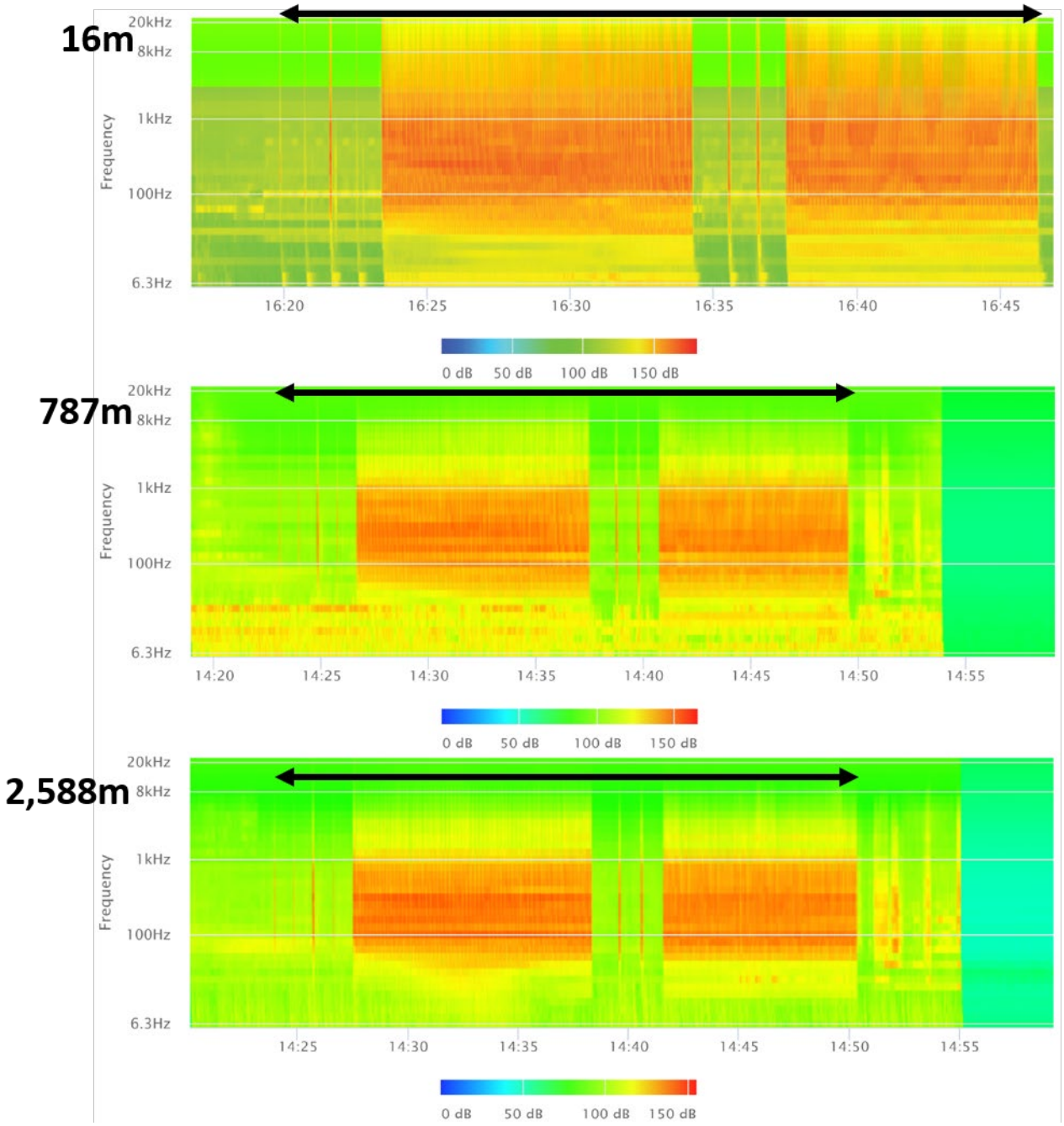

Figure C-41. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile B-1 on June 16, 2020

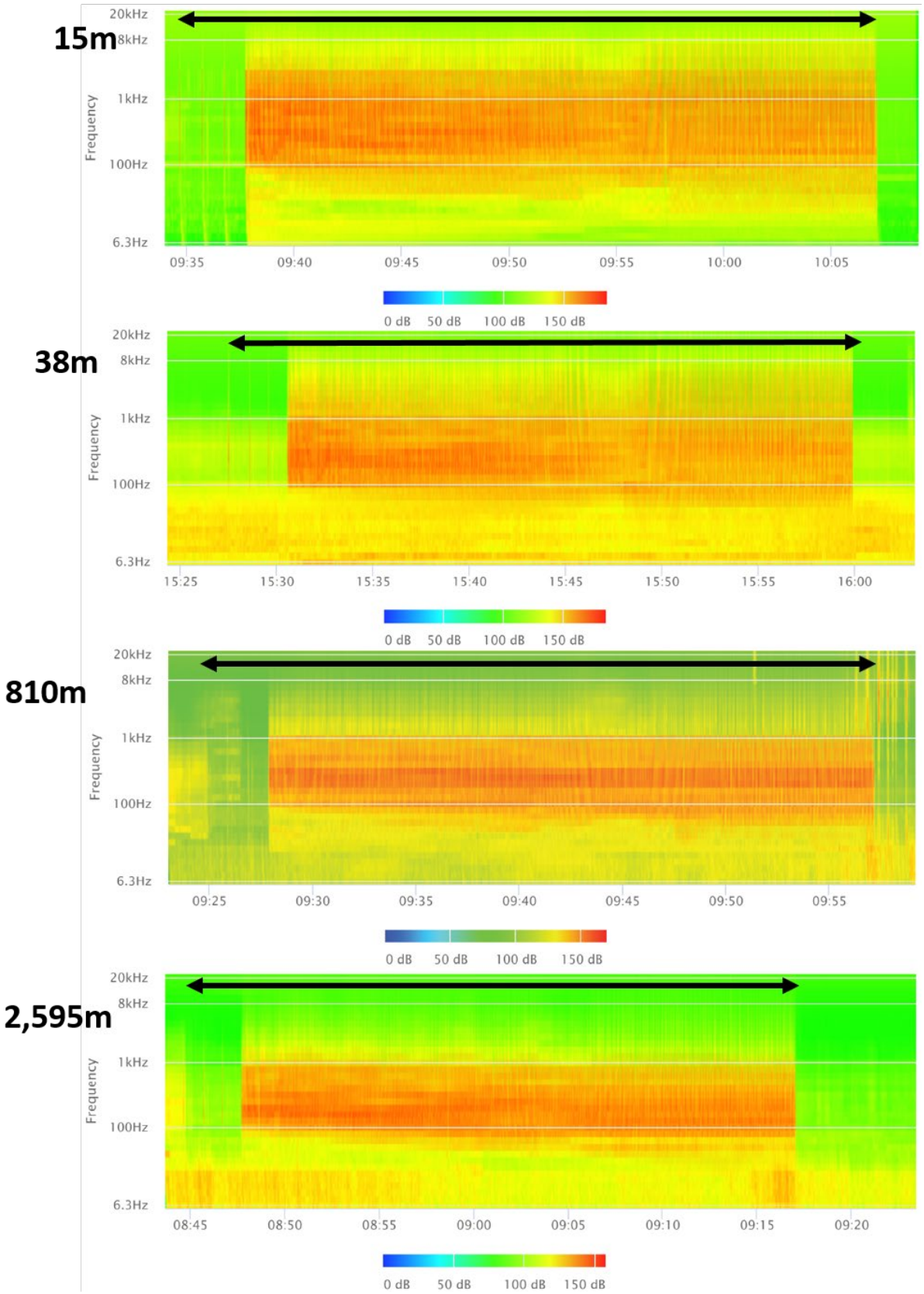

Figure C-42. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile E-4 on June 19, 2020

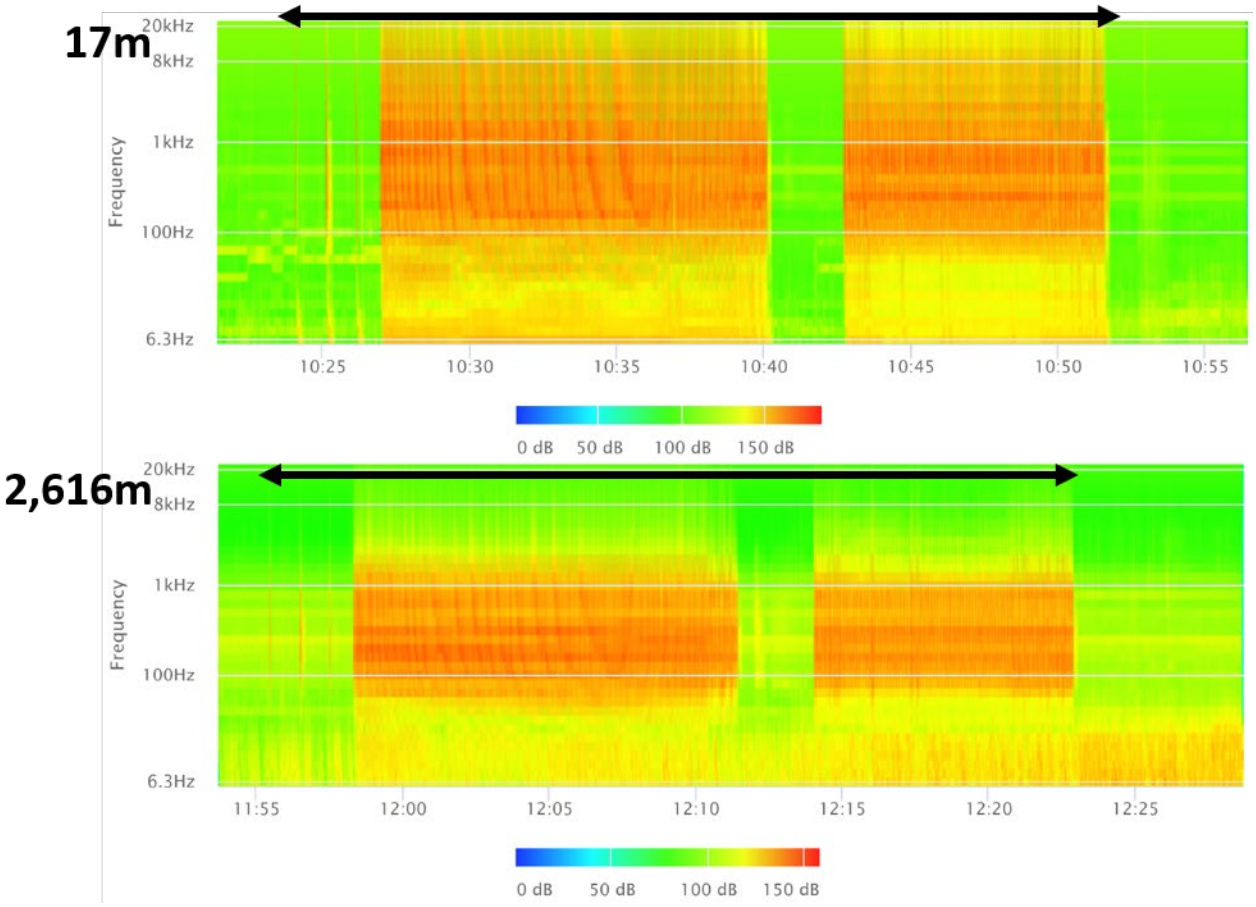

Figure C-43. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile GT-3 on June 20, 2020

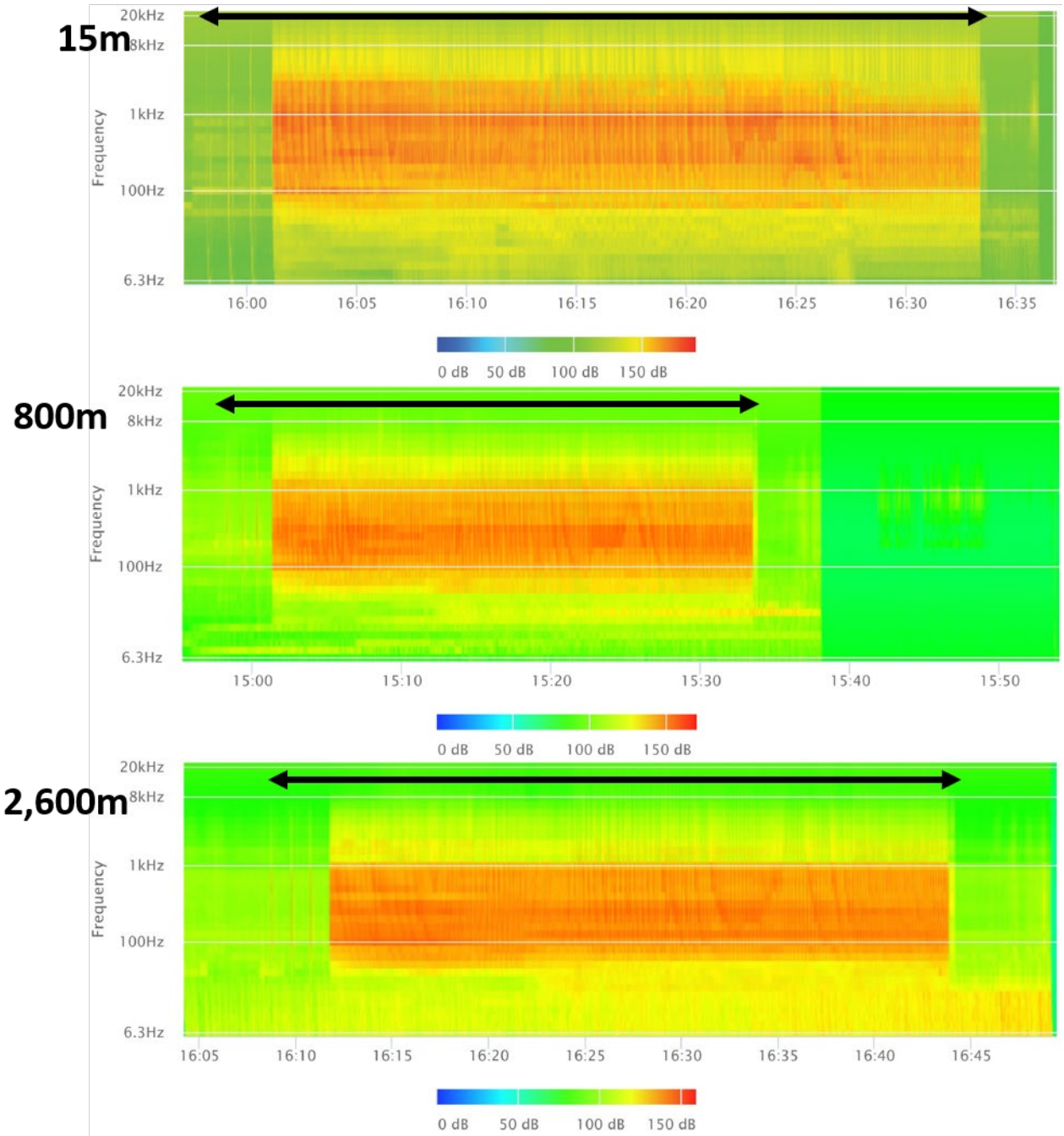

Figure C-44. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile B-5 on June 23, 2020

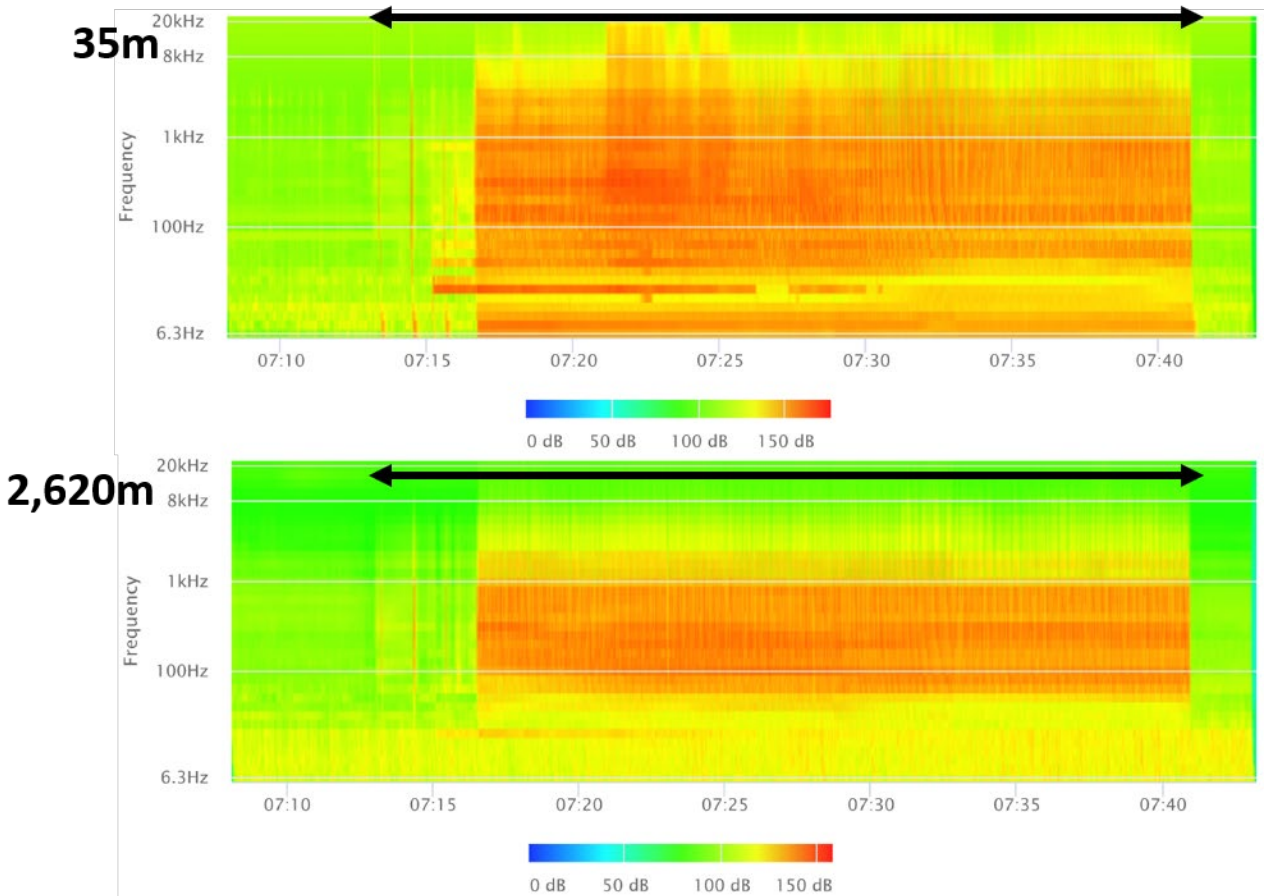

Figure C-45. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile D-5 on June 24, 2020

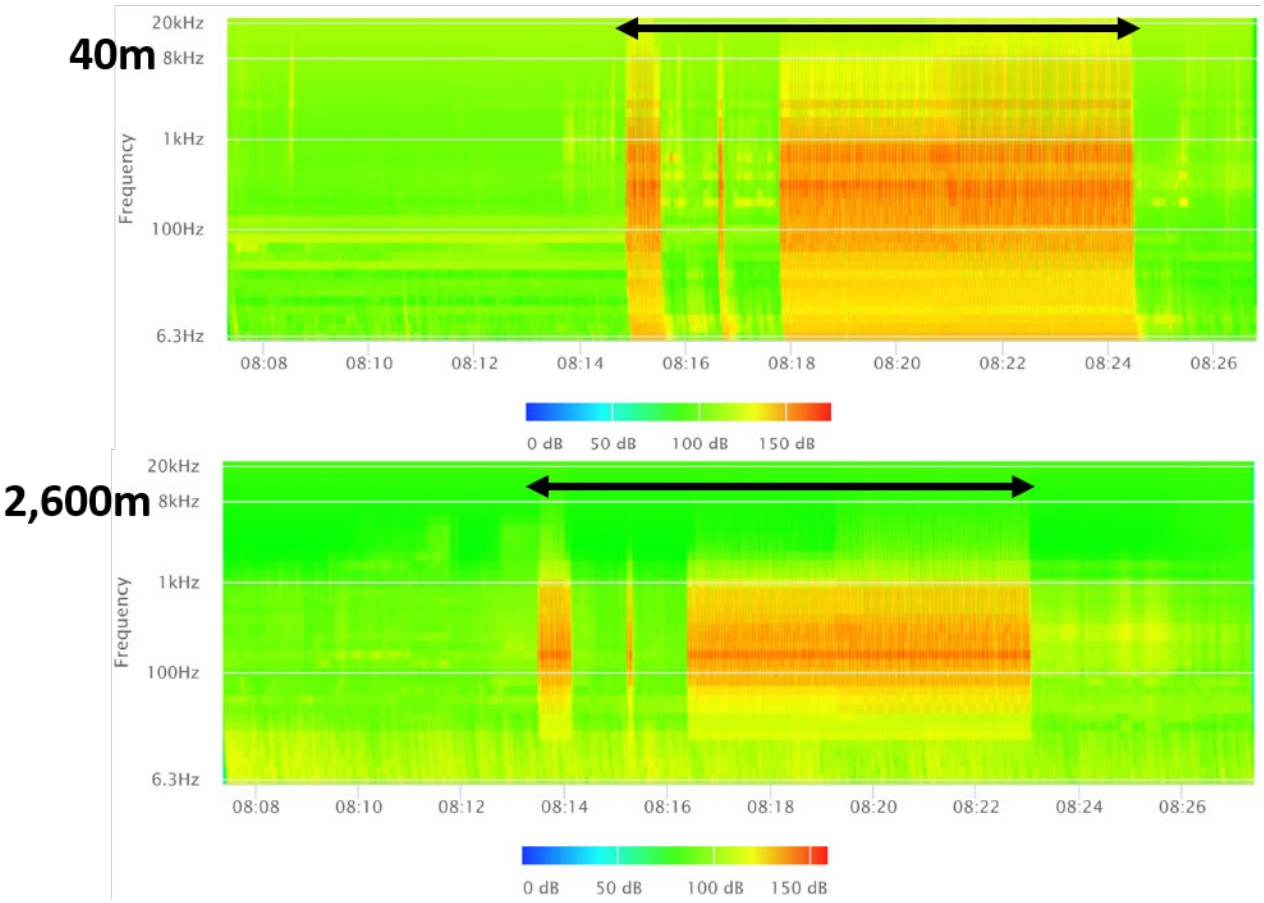

Figure C-46. Spectrogram plots for each measurement location in the westward direction during the impact driving of Pile A-1 on June 24, 2020