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There has been a growing concern in recent years about the effects of anthropogenic noise due to marine pile driving on underwater wildlife. Current guidelines for mitigating hydroacoustic effects associated with these events are based upon relatively simple transmission loss formulations. The advantage to these guidelines is that computing transmission loss using their prescribed methods is not labor intensive, but their disadvantage is that they may not take all variables into account. Because of this, it may be possible to improve transmission loss computations. To better-characterize marine pile driving sound transmission loss, a unique in-water instrumentation system was developed. This system consists of several hydrophone-equipped buoys that transmit sound data to a field team in real time via a wireless network. The sound data are also recorded onboard the buoys along with geospatial data and water temperature data at depth. Testing was conducted using this buoy system at various water-based pile driving sites throughout Florida and sound data were used to compute transmission loss as a function of distance from the sound sources to utilize data from these sites to improve the knowledge base associated with generating mitigation guidelines. This research found that the coefficients used to calculate the simplified transmission loss model were consistently above those recommended by the current set of guidelines. Future areas of improvement and additional testing are recommended to address the growing concern of anthropogenic noise on underwater wildlife species and the effects of underestimating the actual transmission losses.

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AN ANALYSIS OF HYDROACOUSTIC TRANSMISSION LOSS ASSOCIATED WITH MARINE PILE DRIVING

By

JONATHAN BERUBE

A Thesis submitted to the Department of Civil Engineering

in partial fulfillment of the requirements for the degree of

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Dedication

This work is dedicated to my wife Chelsea for all her love and continued support.

Acknowledgments

I would like to thank my advisor, Dr. Raphael Crowley, for all the knowledge, mentorship, and assistance that he has provided me over the course of this thesis and throughout my graduate degree. He has also been the main spokesperson for the continued Navy presence within the University of North Florida coastal program. I honestly could not have completed this work without his continued guidance and support.

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Abstract

There has been a growing concern in recent years about the effects of anthropogenic noise due to marine pile driving on underwater wildlife. Current guidelines for mitigating hydroacoustic effects associated with these events are based upon relatively simple transmission loss formulations. The advantage to these guidelines is that computing transmission loss using their prescribed methods is not labor intensive, but their disadvantage is that they may not take all variables into account. Because of this, it may be possible to improve transmission loss computations. To better-characterize marine pile driving sound transmission loss, a unique in-water instrumentation system was developed. This system consists of several hydrophone-equipped buoys that transmit sound data to a field team in real time via a wireless network. The sound data are also recorded onboard the buoys along with geospatial data and water temperature data at depth.

Testing was conducted using this buoy system at various water-based pile driving sites throughout Florida and sound data were used to compute transmission loss as a function of distance from the sound sources to utilize data from these sites to improve the knowledge base associated with generating mitigation guidelines.

This research found that the coefficients used to calculate the simplified transmission loss model were consistently above those recommended by the current set of guidelines. Future areas of improvement and additional testing are recommended to address the growing concern of anthropogenic noise on underwater wildlife species and the effects of underestimating the actual transmission losses.

Chapter 1: Introduction and Background Information

1.1 Introduction

As construction efforts have increased with new technologies and the development of coastal areas and waterways within the United States, there has been a rising concern about the effects of anthropogenic noise due to marine pile driving on underwater wildlife. While this noise can be loud and intrusive to the human ear, it has the potential to cause harm and/or death to marine life when performed in underwater environments. These environmental risks play a large role in permitting and the construction of bridges, wharfs, piers, and dock systems throughout the United States. The cost and timelines for both construction and environmental permitting is affected due to the anticipated noise-levels and the requirement of sound attenuation devices, such as bubble curtain, during pile driving activities. Current guidelines for the calculation and mitigating the effects of noise on underwater wildlife associated with pile driving activities are based upon simplified transmission loss formulas.

1.2 Background

In 2009, ten federal agencies, as a part of the Joint Subcommittee on Ocean Science and Technology, formed an interagency task force on anthropogenic sound and the marine environment. As a result of this task force, agencies agreed on high priority research recommendations to (1) develop and validate mitigation measures to minimize demonstrated adverse effects from anthropogenic noise; (2) test/validate mitigating technologies to minimize sound output and/or explore alternatives to sound sources with adverse effects; and (3) explore the need for and effectiveness of time/area closures versus operational mitigation measures. Following this interagency task force, the National Marine Fisheries Service (NMFS) developed the Ocean Noise Strategy initiative to articulate NOAA's vision for addressing ocean noise impacts over the next ten years and guide management actions towards that vision. In November 2016, NMFS approved the Ocean Noise Policy, which required NMFS to address noise impacts to species and their habitats over the next ten years in accordance with the Ocean Noise Strategy Roadmap. With this policy, NMFS is beginning to have more focus on projects with noise impacts such as those that require in-water pile driving.

In December 2016, the Federal Highway Administration (FHWA) assigned all federal National Environmental Policy Act (NEPA) responsibilities to the Florida Department of Transportation (FDOT). This memorandum of understanding required the FDOT Office of Environmental Management to ensure the NEPA process is completed on all federal roadway projects statewide. This includes conducting species consultations as needed. During the environmental review process, agency representatives from NMFS and United States Fish and Wildlife Service (USFWS) have repeatedly expressed concerns about the effects that pile-driving activities have on Florida's protected species. The required species consultations are taking place project by project and do not always have predictable outcomes. Considering the recent initiatives set forth by NOAA, these concerns are anticipated to become more frequent and have the potential to set higher standards for mitigation on transportation projects. This could potentially slow the review process or delay projects by requiring the incorporation of new sound attenuation techniques. Sound attenuation devices such as bubble curtains, cofferdams, or double piles (Reinhall et al. 2015) are expensive and may significantly increase project cost.

1.3 Transmission Loss Models

The guidelines that are currently utilized for mitigating hydroacoustic effects associated with pile driving are based upon relatively simple transmission loss formulations. The advantage of utilizing these simplified models is that the computation of transmission loss is relatively straightforward. The disadvantage of these simplified formulations is that they may not take all variables into account when computing transmission loss. In particular, they do not include water temperature, wave climate data, and/or local geotechnical information which may affect the transmission loss.

Both the simplified models and a few of the more sophisticated models are discussed in the sections below. Two quantities are of particular interest in the context of anthropogenic noise that may harm marine wildlife – cumulative sound exposure level (*SEL)* and transmission loss (*TL)*. *SEL* refers to cumulative sound exposure-level integrated over a certain length of time, usually a day. Transmission loss on the other hand is a measurement of sound attenuation over some distance.

1.3.1 Simplified Models

The mechanisms that cause *TL* have been discussed by several authors over the years. Weston (1971) provides one of the better, earlier summaries of these efforts. In general, as discussed by Weston (1971), *TL* is governed by a number of different solutions to the Helmholtz Equation depending on distance from a point sound source like a pile drive. Closer to the pile, spherical spreading tends to dominate wherein *TL* may be computed via:

$$TL = -10\log_{10}\left(\frac{I}{I_0}\right) = 10\log_{10}(R^2) = 20\log_{10}\left(\frac{R}{R_o}\right) \quad (1\text{-}1)$$

Note that *TL* is measured in decibels (i.e., $dB_{in} - dB_{out}$); *R* is the range from the sound source which is usually divided by some reference range, R_o; *I* is transmitted sound intensity; and I_0 is the incoming sound intensity. On the other hand, further from the pile, *TL* tends to be dominated by cylindrical spreading:

$$TL = -10\log_{10}\left(\frac{I}{I_0}\right) = 10\log_{10}\left(\frac{R}{R_o}\right) \quad (1\text{-}2)$$

Buehler et al. (2015) recommend splitting the difference between spherical and cylindrical spreading when describing *TL* during pile driving by using the "practical spreading loss model":

$$TL = 15\log_{10}\left(\frac{R}{R_o}\right) \quad (1\text{-}3)$$

In a more generic sense, these equations express *TL* as a function of a constant times the base-10 logarithm of the range:

$$TL = F\log_{10}\left(\frac{R}{R_o}\right) \quad (1\text{-}4)$$

Both the spherical and cylindrical spreading loss models, and by extension their halfway point, represented by the practical spreading loss model, are derived directly from incoming/outgoing sound power over some assumed area. The advantage to this sort of analysis is that it is very simple for design engineers to use, but its disadvantage is that none of these *TL* models take sound absorption into account. Absorption usually would be caused by sound waves interacting with geometrical boundaries such as the ocean floor, the water surface, or other obstructions.

1.3.2 More Sophisticated Noise Propagation Models

More-complicated models are available that take absorption into account. These sorts of models fall into three categories – ray theory models as summarized by Tucholski (2006) and later programmed by Etter (2009); normal mode models as presented by Jensen et al. (2011) and Porter (1992); and parabolic models as discussed by Collins (1993). As discussed by Farcas et al. (2015) each of these models is appropriate for different water depths (i.e., deep water versus shallow water) and sound frequencies (high versus low frequency). In Figure 1-1, RI = range independent; RD = ranged-dependent, black cells indicate modeling approach is applicable and computationally efficient, gray cells indicate limitations in accuracy or computational efficiency; and the white cells indicate the modeling approach is neither applicable nor practicable.

Table 1-1. Applicability of common sound propagation models (Adapted Farcas et al. 2015).

Model Type	Shallow Water				Deep Water			
	Low-Frequency		High Frequency		Low Frequency		High Frequency	
	RI	RD	RI	RD	RI	RD	RI	RD
Ray Theory								
Normal								
Parabolic								

In addition, as discussed by Etter (2009), multipath expansion models and fast field models may also describe underwater sound propagation, but these models tend to be inappropriate for shallow water. High-frequency sound is usually described as sound frequencies greater than 500 Hz (Etter, 2009). Range-dependence refers to the noise environment. A model that permits horizontal variations in the environment – things such as a sloping bottom or spatially variable oceanography – is termed *range dependent* while models that do not take these variations into account are termed *range independent* (Jensen et al., 2011). From a practical perspective then, the most appropriate more sophisticated model-types for describing underwater noise propagation due to pile driving in Florida appear to be:

- Ray theory models for higher frequency pile driving noise in environments where bathymetry data are known. This would likely be from vibration installation.
- Parabolic models for lower-frequency pile driving noise in environments where bathymetry data are known. This would likely be from more-traditional hammer installations.
- Normal-mode models for both low-frequency and high-frequency pile driving noise in environments where bathymetry data are unknown.

Unfortunately, a “catch all” model may not exist that would be appropriate for every waterbody. This is because underwater sound propagation is described by harmonic solutions to the wave equation, which in turn is described by the Helmholtz equation.

1.3.3 Practical Spreading Loss Model vs Range-Dependent Acoustic Model

Through a series of simultaneous pile driving tests, Farcas et al. (2015) compared the practical spreading loss model to a parabolic equation model based on Range-Dependent Acoustic Model (RAM). They concluded that the practical spreading loss model underestimates noise in the vicinity of the source and grossly overestimated noise farther from the source. A graphical representation of their findings is in shown in Figure 1-2. Graph (a) is based on the spreading loss model, (b) is based on the RAM model, and (c) is the difference between two models. From graph

(a) it is visually distinguishable that the spreading loss model depicts a much lower rate of sound transmission loss when compared to the of the RAM model.

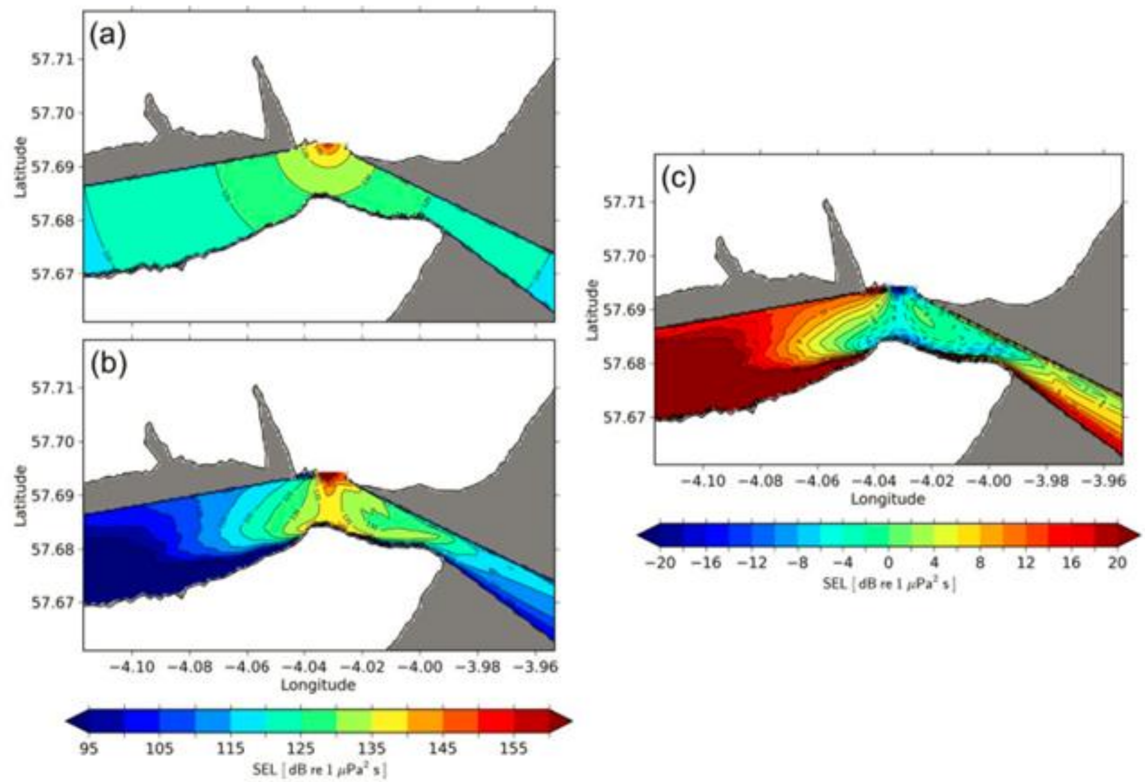


Figure 1-1: Maps of sound levels received for a pile driving operation (Farcas et al., 2015)

Eventually, it may be possible to adapt some of these models to better-predict underwater noise due to pile driving, but this effort may be complicated and the result may be difficult to implement. In recent years, several researchers have instead sought to calibrate Equation 1-4 using field data. Buehler et al. (2015) discussed these efforts and noted that using an approach similar to Equation 1-4 could yield a range of values for *F* from 5 to 30.

1.4 Goals and Objectives

The goal of this research was to retrieved sound data to obtain a calibrated *F-value* and measure the *SEL* for various water bodies within Florida. The sound data was measured using a series of buoy systems at various pile driving sites. Then, using a best-fit regression curve to fit the data, *F-values* were approximated for each testing site. Subsequently, these *F-values* were compared to the practical spreading loss model, *F-value* of 15, which is typically utilized for mitigating hydroacoustic effects associated with pile driving.

1.5 Thesis Organization

This thesis is organized into chapters as follows:

- Chapter 2 provides information on the instrumentation system;
- Chapter 3 details information on the methodology;
- Chapter 4 presents specific site details and the collected raw data;
- Chapter 5 presents the analysis of the collected sound data;
- Chapter 6 provides conclusions and future recommendations.

Chapter 2: Data Acquisition Equipment

This chapter provides an overview of the data acquisition equipment used to develop, deploy and record data using a hydrophone-based sound collection system.

2.1. Flotation Components

Investigators used buoys as a platform for a hydrophone-based sound collection system. Buoyancy was achieved by using two small pontoons. An aluminum frame was affixed to each buoy's pontoons using a pin connection. The aluminum frames shown in Figure 2-1 consist of 2-inch by 1-inch aluminum rectangular tubing; 2-inch by 2-inch aluminum angle sections; and a small aluminum plate to hold the Wi-Fi antennae. The aluminum frames were welded so that they would be water-tight.

To connect the frames to the pontoons, pin-connections were required. To make these connection water-tight, holes were drilled through the aluminum tubing, and small cylindrical sections were inserted into these holes and welded into position.

Figure 2-1. Pontoons, Pelican case, and aluminum frame.

2.2 Water-Tight Boxes and Connections

Each frame holds a Pelican™ 1450 box that houses the electronics associated with the instrumentation system. Scanstrut cable clam/deck seals were used to pass a hydrophone cable and a thermocouple cable from the exterior into the box while a MENCOM MDE45-8FR-RJ45-BM waterproof Ethernet connection was used to route an Ethernet cable into the case. A photograph of all these connections is shown in Figure 2-2.

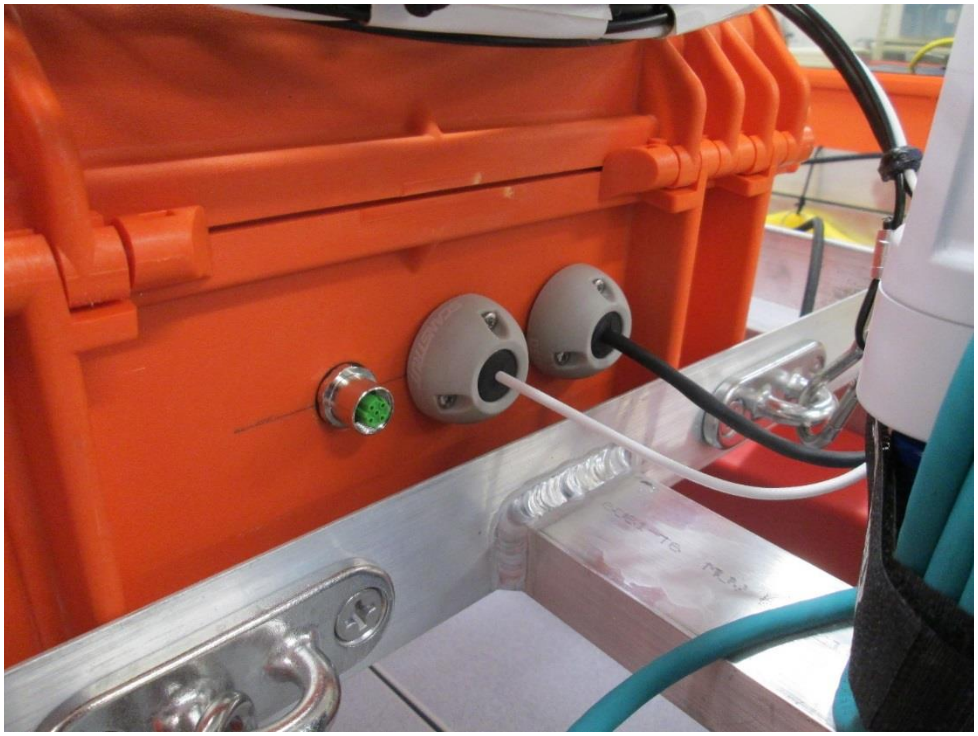


Figure 2-2. Ethernet, hydrophone, and thermocouple connections.

Electronics in the case consist of Bruel and Kjaer 2250 handheld analyzers; Bruel and Kjaer 2647 charge converters; L-Com BT-CAT5-P1 power-over-Ethernet converter; two 12-volt motorcycle batteries connected in series; and Pace Scientific XR-440M pocket loggers for the thermocouples. Outside of each box are a Pace Scientific PT960 temperature probe; a Bruel and Kjaer 8103 hydrophone; a Ubiquiti Bullet M2 wireless access point; and an L-COM HG2409UP antenna. The batteries, power converter, Bullet, and antenna connect to the handheld analyzer via Ethernet cable and broadcast sound data to a computer in real-time. In addition, i-gotU GT-600 GPS units were added to each box to track location. An overview of the electronics is located in Figure 2-3.

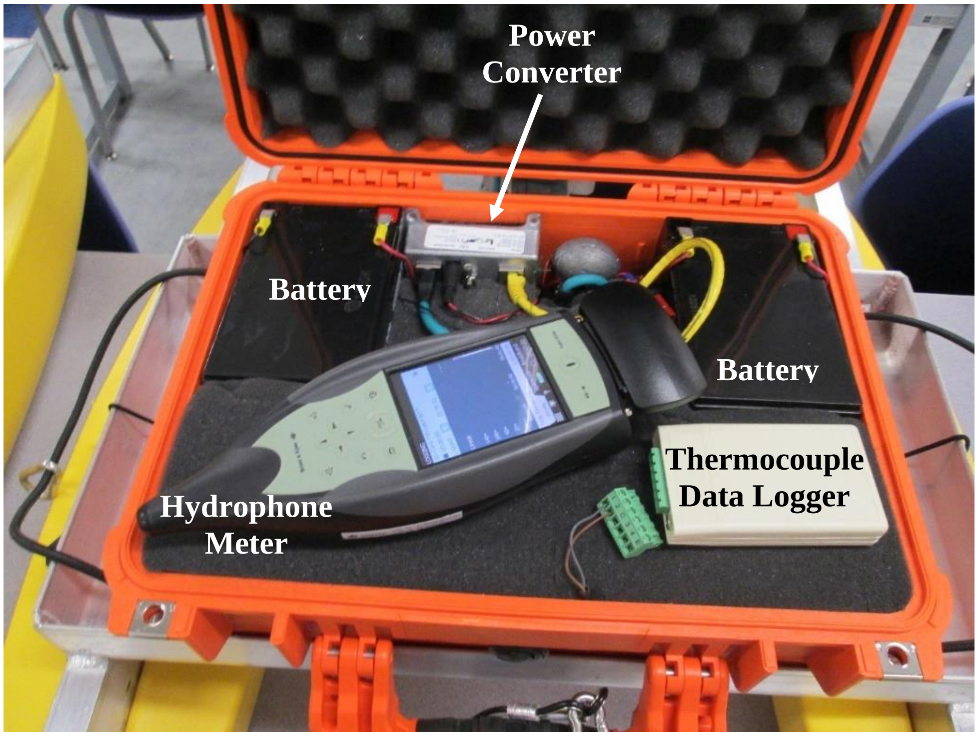


Figure 2-3. Electronics inside data collection box.

The stainless steel, hydrophone, and thermocouple cables were connected using a series of cinch knots (Figure 2-4). The knots and stainless-steel cables provide a strain relief system and strength member to support the weight as opposed to the hydrophone/thermocouple cables. The cable bundle length of 40-feet and evenly spaced cinch knots ever 18-inches, allows incremental testing in water depths ranging from 3-feet to 80-feet.

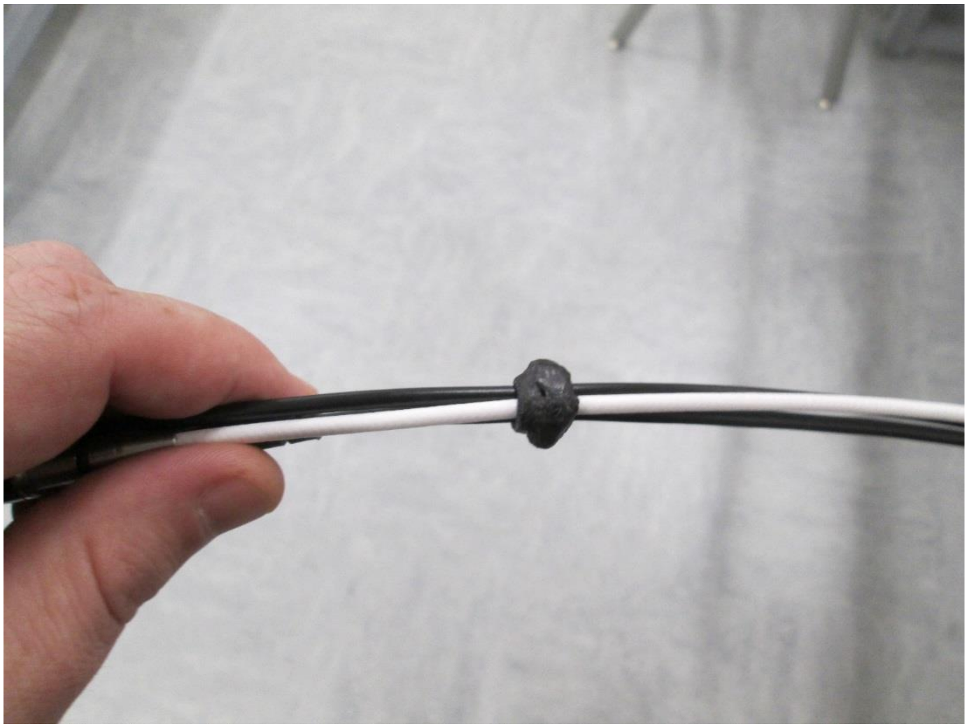


Figure 2-4. Cinch knot used to join the cables.

A loop was crimped onto the end of each stainless-steel cables so that it could be used to attach the weight (Figure 2-5). To use the strain relief system, one carabiner is clipped to the loop in the end of the steel cable and the deck clip closest to the bulkhead connectors (i.e. the clip on the right-hand side of Figure 2-6). This provides strain relief for the bulkhead connections. The other carabiner is clipped to the other deck clip to provide strain relief for the hydrophone/thermocouple cables and to provide a mechanism for lowering the cables to their proper depths (clip on the left in Figure 2-6). When the cables are deployed, this carabiner is clipped to the cinch knot corresponding to the appropriate depth.

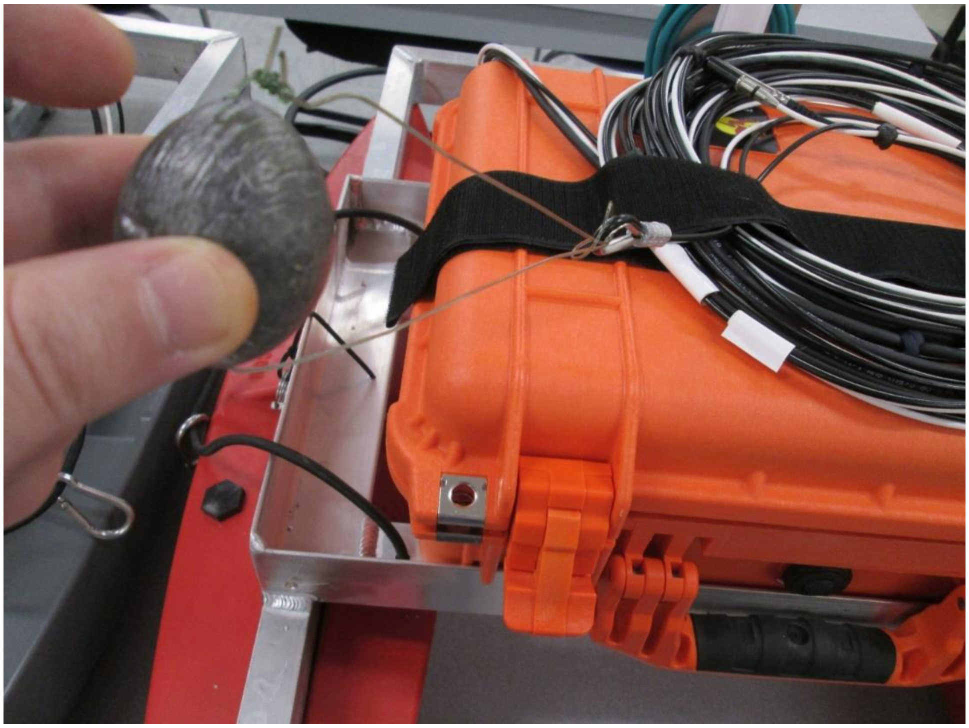


Figure 2-5. Cable loop and weight.

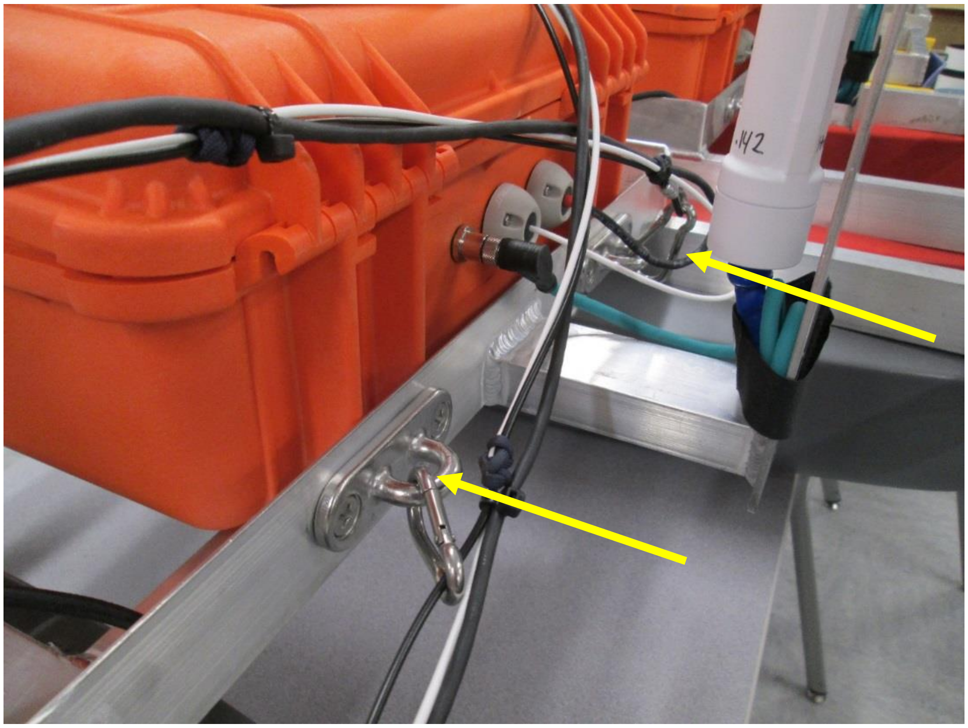


Figure 2-6. Strain relief connections.

An industrial Velcro strap was adhered to the box lids for storing/coiling both excess cable and/or the cables when not in use. The excess cable can be coiled manually and strapped to the top of the box. A labeled overview of the entire data collection buoy system is located in Figure 2-7.

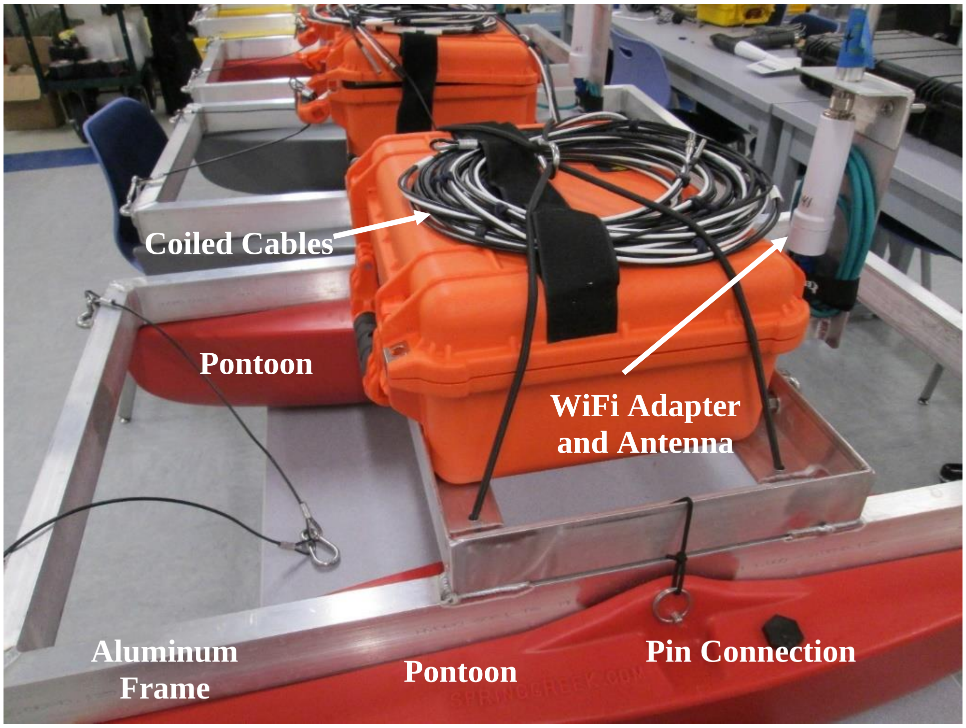


Figure 2-7. Labeled overview of the data collection buoy.

2.3 Bridle and Anchoring System

To anchor the buoy systems in place during testing, one river anchor was obtained for each buoy. A photograph of two of these river anchors is presented below in Figure 2-8:

Figure 2-8. River anchors.

Anchor bridles were affixed to each data collection buoy using stainless-steel deck clips that were attached to the buoys' aluminum frames via a heat activated metal epoxy (Figure 2-9). Under strong current conditions, these anchor bridles will position the buoys further away from their anchor lines thereby minimize the risk for tangling between the anchor lines and the data collection cables.

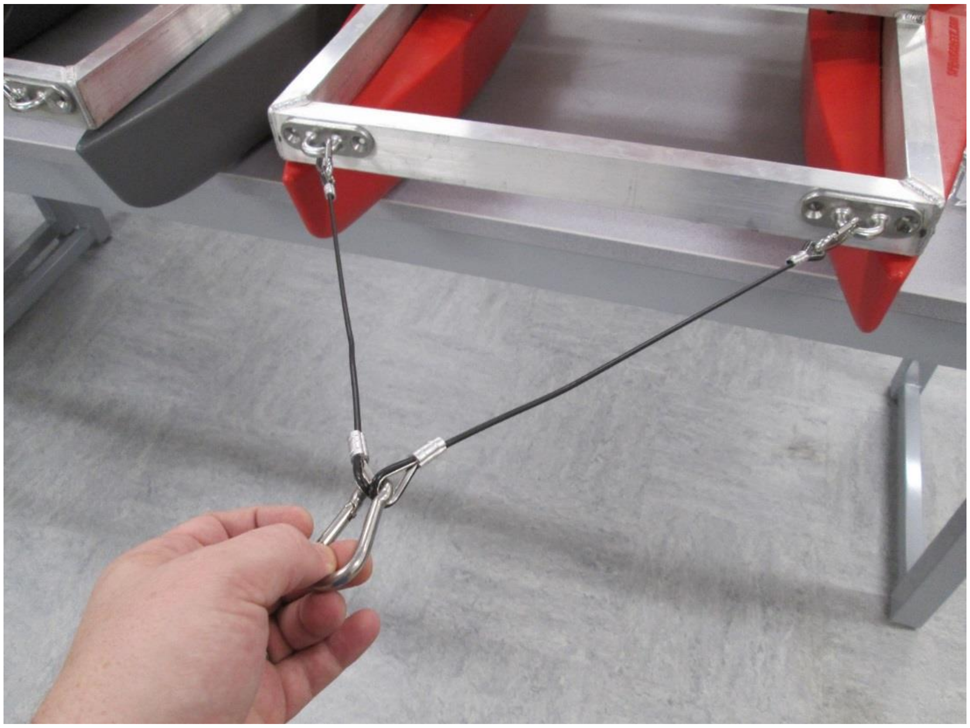


Figure 2-9. Anchor bridle system.

Polypropylene rope was obtained to affix the buoys to their anchors. While the polypropylene rope floats, it was noted that it may be difficult to retrieve from the field watercraft under wavy conditions. In addition, during deployment, it would be difficult to simultaneously launch both the anchors and the data collection buoys. Therefore, five small plastic buoys were obtained and the anchor lines were connects to the smaller buoys (Figure 2-10). Then, the data collection buoys are connected to these smaller buoys. As such, the field team could sequentially deploy the anchor and then deploy the data collection system. During pickup, this setup allows the field team to retrieve the anchor first and then the data collection buoy.

Figure 2-10. Small plastic buoys.

2.4 Deployment of Buoys

During field testing the buoys were loaded onto a watercraft to deploy. Figure 2-11 provides a photograph of the loaded buoys, two stacked on top of one another front to back so that their antennae did not interfere with one another. Prior to the deployment of buoys at each testing site, the hydrophones were calibrated in a quiet setting to ensure accuracy. Also the ambient noise levels were measured for at least 60 minutes either before or after the pile driving.

Figure 2-11. Watercraft loaded with buoys.

Once the watercraft is in position at the site, and the water depth has been determined, the buoys were deployed once all internal components were connected and turned on. Figure 2-12 provides a typical data collection buoy set up deployed as a test run in the Intracoastal Waterway near Jacksonville Beach, Florida.

Figure 2-12. Data collection buoys deployed in the Intracoastal Waterway near Jacksonville Beach, FL.

Chapter 3: Methodology

This chapter provides the methodology for capturing and utilizing the LZ_{peak} data along with the mathematical analysis used to determine an approximation of *F* at each testing site.

3.1 Use of LZ_{peak} Data

Following the approaches of previous literature, the analysis was focused on capturing and using LZ_{peak} data. This means that these data represent the maximum, unweighted (i.e. Z-weighted) sound-level measured each second. The Z-weighted sound-level is a flat frequency indicating that no weighting is present across the audio spectrum whereas an A-weighted sound-level filters sound based upon the limits associated with human hearing. The differences between the A and Z-weighted frequencies curves are shown by Clarke Roberts (2011) in Figure 3-1.

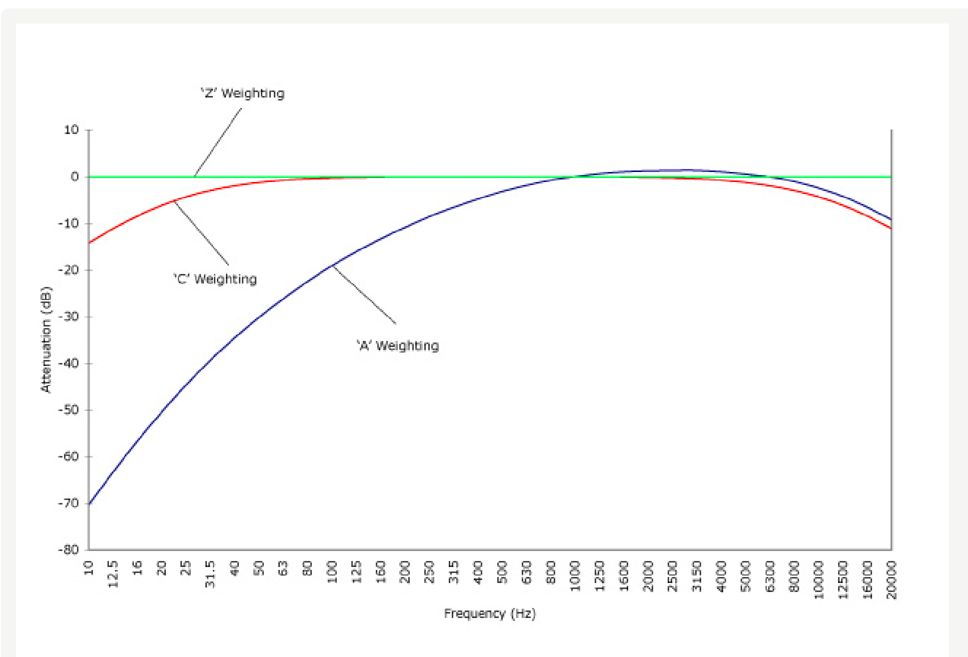


Figure 3-1. Frequency Weighting Curves – 'A', 'C', & 'Z' (Roberts, 2011)

While these LZ_{peak} data show oscillations (as would be expected), these oscillations should not be interpreted as "hammer blows." This is because the impact rate of the hammer may be much faster than the 1-s logging rate shown in the LZ_{peak} data and the hammer will often be out-of-phase with a 1-s logging rate. This will be illustrated using an example from the Ribault River Test Pile using the data from the buoy closest to the pile as shown below in Figure 3-2:

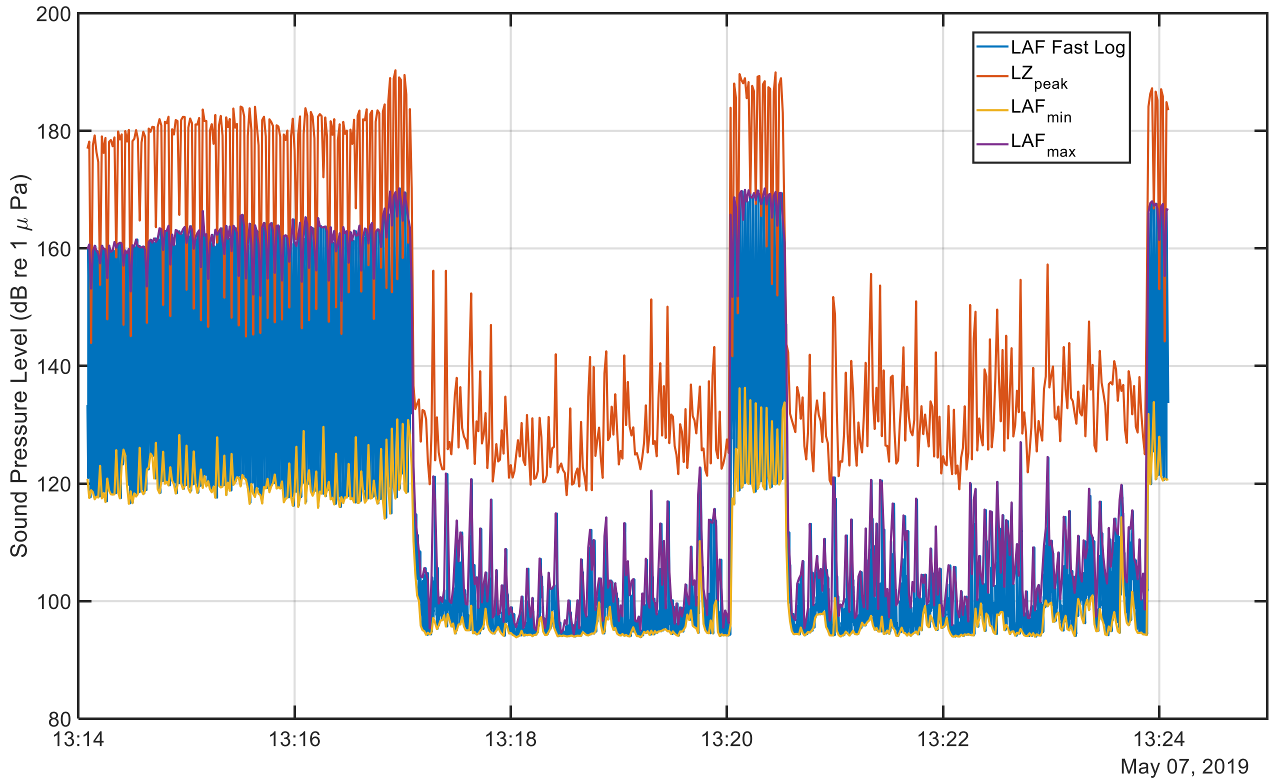


Figure 3-2. Different logging values from Ribault River test pile.

In addition to LZ_{peak} data, three other values are also shown in Figure 3-2:

- LAF Fast Log: these data are average A-weighted sound-level measured every hundredth (i.e., 0.01) second. Each oscillation in these data represents a hammer blow.
- LAF_{min}: these data are lowest A-weighted sound-level measured every second. While the data oscillate (similar to the LZ_{peak} data), these oscillations should not be interpreted as hammer blows.

- LAF_{max}: these data are the highest A-weighted sound-level measured every second – similar to the LZ_{peak} data except A-weighted instead of Z-weighted. Again, while these data oscillate, these oscillations should not be interpreted as hammer blows nor should they be interpreted as "true maxima" since A-weighting tends to attenuate some of the higher-frequency maxima that cause the most intense sound-levels

Zooming in on a portion of the data illustrates a better picture of each hammer blow as shown below in Figure 3-3:

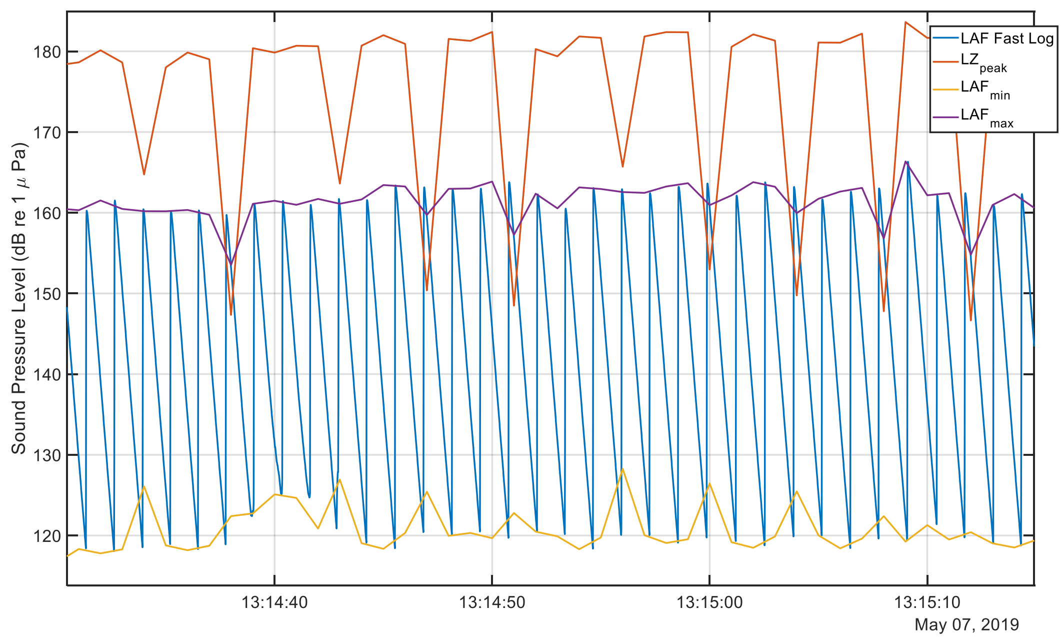


Figure 3-3. Zoomed-in logged data from Ribault River test pile

As shown, the LAF data oscillate at a rate of approximately one hammer blow every 1.2 seconds that is only in-phase with a 1-s time-marching algorithm every 5 blows. In other words, starting at t = 0, the first blow would complete at t = 1.2 s; the second at t = 2.4 s; and so on. If one picks the peak LAF value from t = 0 to t = 1.2 s, they will be left with a large "spike" in sound (correctly). However, if one picks the peak from t = 1 s to t = 2 s, the corresponding data point will not be a true "peak" relative to the actual noise signal. Put another way, time-averaging, time-maximizing, and time-minimizing over a relatively large timestamp like 1 s results in aliased signals. Likewise, time-averaging A-weighted sound-level per 0.01-s results in a signal that does not reach the same maxima one would get using LZ_{peak} data since A-weighting tends to attenuate some of the higher-frequency sound-levels. As such, LZ_{peak} represents the worst-case recorded signal and was therefore used throughout this analysis. This is believed to be common as other studies in the literature also reported using LZ_{peak} data for their analysis.

3.2 Mathematical Analysis

This section discusses the mathematical analysis used in order to apply the concepts of previous literature to determine *SEL* and *TL*, and ultimately the approximation of *F*. These data were used to compute the following:

- Root-mean-squared sound pressure across 90% of the data – i.e., RMS_{90} during each drive or vibration event
- The peak sound pressure defined as the instantaneous absolute sound pressure value – i.e., L_{max} during each drive or vibration event
- The sound exposure-level (*SEL*) across 90% of accumulated sound energy – i.e., SEL_{90} – computed during each drive or vibration event
- The cumulative *SEL* – i.e., SEL_{cum} during each drive or vibration event

SEL is defined below in Equation 4-1:

$$SEL = 10\log_{10}\int_0^T P^2(t)dt \qquad (3\text{-}1)$$

where *P* is the instantaneous sound pressure data; and *T* is the appropriate integration limit corresponding to either all the sound-level measurements (for SEL_{cum}) or the lower 90% of sound-level measurements (for SEL_{90}). From a mechanics perspective, Equation 3-1 requires some manipulation because the hydrophones return sound information in decibels relative to 1 μPa. As such, to get sound pressure:

$$P = P_{ref} 10^{\frac{LZ_{peak}}{20}} \tag{3-2}$$

where P_{ref} is the reference pressure of 1 μPa. To perform the integral of *P*, a simple trapezoidal numerical integration algorithm was employed. Once P^2 had been integrated, *SEL* was computed using the following expression:

$$SEL = 10 \log_{10} \frac{\int P dt}{P_{ref}^2} \tag{3-3}$$

In some of the previous literature by FDOT, others used the following approximation for *SEL*:

$$SEL \approx \overline{(LZ_{peak})} + 10 \log_{10} T \tag{3-4}$$

where *T* is the time of the sound event and the overbar denotes a mean. Results were checked using this approximation to ensure accuracy.

Transmission loss, *TL* (in decibels relative to 1 μPa) is known to be a function of the base-10 logarithm of the range from the sound source as shown below in Equation 3-5:

$$TL = F \log_{10} \left(\frac{R}{R_0}\right) \tag{3-5}$$

where *R* is the range from the sound source; R_o is some reference range (usually 1-m) and *F* is the transmission loss coefficient. One may rewrite Equation 5-5:

$$P_s - P_B = F \log_{10} \left(\frac{R}{R_0}\right) \tag{3-6}$$

where P_s is the sound pressure at the source and P_b is the sound pressure at a buoy. Rearranging:

$$P_B = P_s - F \log_{10} \left(\frac{R}{R_0}\right) \tag{3-7}$$

Thus, to find F, sound at each buoy may be plotted as a function of range from each pile. Then, a best-fit regression curve of the form:

$$P_B = a\log_{10}\left(\frac{R}{R_0}\right) + b \tag{3-8}$$

may be fit to the data where a and b are best-fit coefficients corresponding to minus-F and P_s respectively.

It has been assumed throughout analysis that P_B corresponds to the enveloped peak data. The concept of an "enveloped peak" warrants further discussion and is best to discuss by example. A typical sound signal from a pile drive is presented below in Figure 3-4:

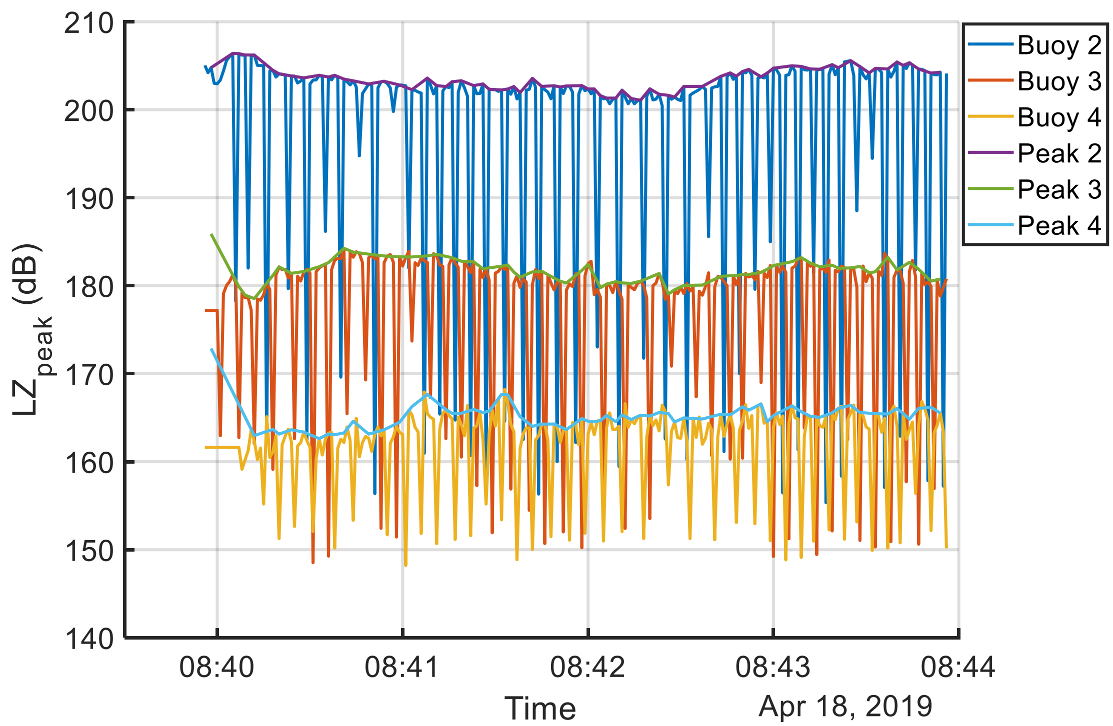


Figure 3-4. Example of typical sound signals during pile driving (Suwannee River Bridge Pile shown).

It is important to note in Figure 3-4, that each signal from each buoy oscillates with a high frequency – as shown in Figure 3-3. Recall that crests/troughs do not correspond to hammer blows because 1-s time maximizing was used. Similarly, one may not expect crests/troughs to exactly align with one another because of the time-maximizing. However, this misalignment is relatively trivial in the context of this thesis since we are interested in (1) transmission loss; and (2) sound exposure level. Therefore, each crest associated with each oscillating noise signal was enveloped using numerical methods. In other words, an algorithm was used whereby each peak associated with each apparent oscillation is found and these peaks are connected. Doing this for each signal allows one to digitize the apparent peaks/crests at each time step. Then, apparent peaks from one buoy may be compared with apparent peaks from another downstream buoy. The built-in MATLAB 'findpks' command performs with enveloping with very little required input from the user. As such, in Figure 3-4, six lines are shown: raw data from Buoy 2, Buoy 3, and Buoy 4 (darker blue, orange, and yellow lines respectively) and enveloped peak data using 'findpks' from Buoy 2, Buoy 3, and Buoy 4 (purple, green, and lighter blue line respectively).

As a check during *TL* computation, quantities mentioned above – i.e., RMS_{90} and L_{max} may be used to fit equations of the form shown in Equation 3-8. In other words, either RMS_{90} or L_{max} for each buoy may be plotted as a function of range from the pile and best-fit regression equations of the form shown in Equation 3-8 may be fit to these data. The corresponding *b* values from these equations represent RMS_{90} and L_{max} at the pile while the corresponding *a* values should be approximately equivalent to *TL* computed using all the data. These computations/plots were performed as well as another check throughout analysis to help ensure accuracy.

To perform these analyses, data were exported to appropriate formats – either comma-separated values (CSV) or American Standard Code for Information Exchange (ASCII). Then, several scripts were written in MATLAB to perform the computations and generate output.

3.3 Wildlife and Ambient Sound Analysis

At each of the testing sites, ambient sound data were estimated by taking an average of sound data when pile driving was not occurring. In addition, Buehler et al. (2015) provide the following table to describe sound's adverse effect on wildlife:

Table 3-1. Guidelines for pile driving adverse effects on fish (adapted from Buehler et al. 2015)

Effect	**Metric**	**Fish Mass (g)**	**Threshold (dB relative to 1 μPa)**
Onset of physical injury	Peak Pressure	N/A	206
	Accumulated SEL	≥ 2g	187
		≤ 2g	183
Adverse behavior effects	RMS Pressure	N/A	150

Both ambient sound data and the appropriate metrics from Table 3-1 were added to the base-10 logarithm charts discussed in Section 3.1 above.

Chapter 4: Site Descriptions and Raw Data

This chapter is divided into the six test site locations and provides an overall site description at each location including the scope of the pile driving activities, site specific information about the data collection process, geotechnical properties and the collected raw data.

4.1 Dunn's Creek Bridge

4.1.1 Site Description

On March 14, 2019, and March 15, 2019, the research team traveled to the Dunn's Creek Bridge just outside of Palatka, Florida in San Mateo, Florida across SR-17. Site location is shown below in Figure 4-1 along with approximate buoy, barge, and pile driving locations.

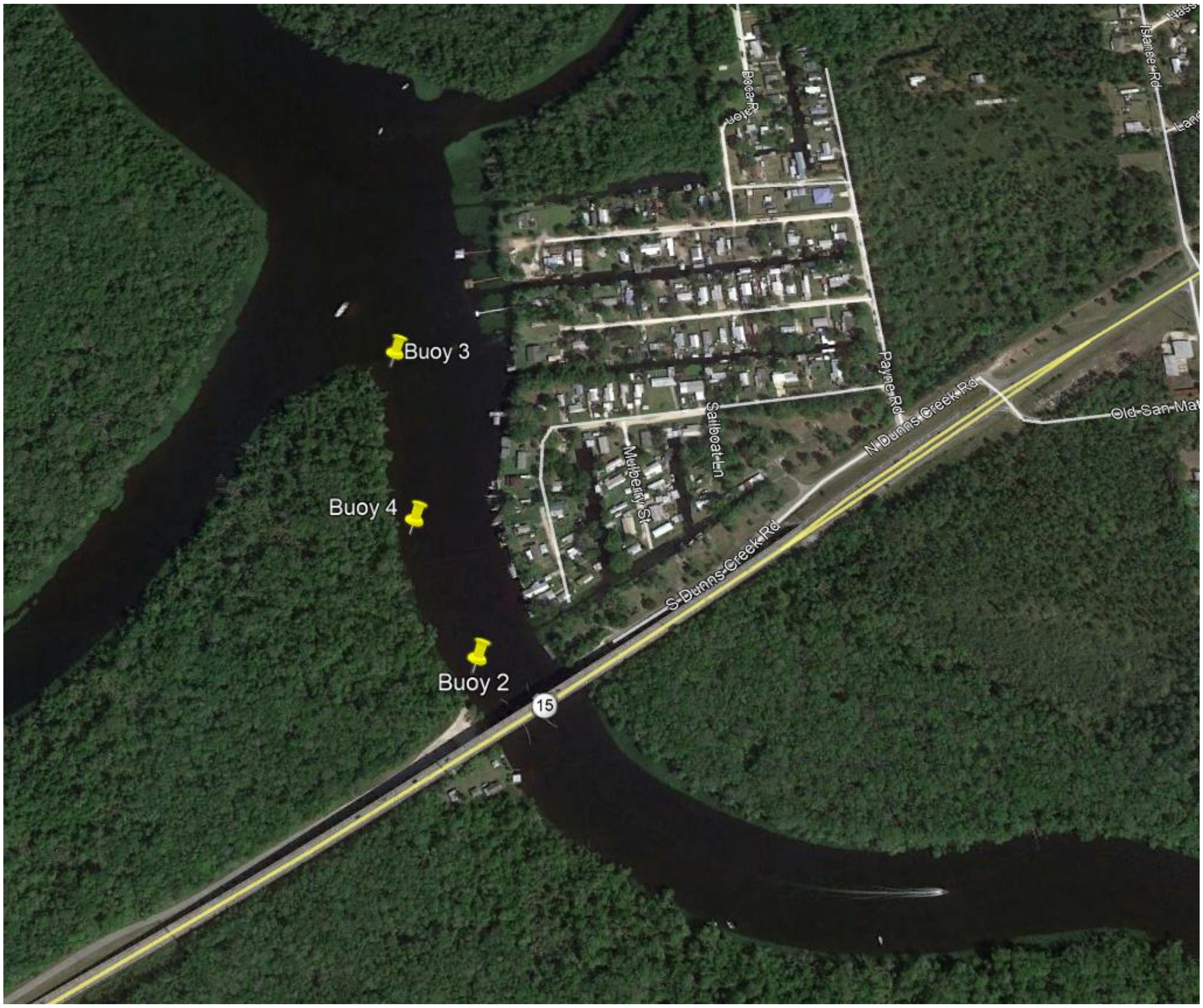


Figure 4-1. Aerial view of Dunn’s Creek Bridge with approximate buoy locations.

4.1.2 Pile Driving Scope

The driving at Dunn’s Creek consisted of vibrating a sheet pile cofferdam using a vibratory hammer as shown in Figure 4-2.

Figure 4-2. Vibrating hammer and sheet pile cofferdam at Dunn's Creek

4.1.3 Data Collection

This site was constrained geographically in the sense that the point near Buoy 3 would have blocked sound further downstream. As such, approximate buoy placement was as follows in Table 4-1:

Table 4-1. Buoy placement summary for Dunn's Creek

Buoy Number	Buoy Distance (m)	Water Depth (m)	Hydrophone Depth (m)
2	59.5	7.62	3.96
4	202.0	6.10	2.74
3	396.0	6.71	3.09

The distances in Table 4-1 were approximated using a laser range finder. However, please note that these approximate distances were reinforced with onboard GPS data. The GPS data were used for data analysis since they are more accurate and account for buoy drift.

On March 14, 2019, no vibrating occurred due to the contractor's hammer malfunctioning and therefore ambient noise data were collected. On March 15, 2019, sheet piles were vibrated in pairs from approximately 10:30 AM through 1:35 PM. However, there were issues with data collection due to malfunctions with several of the buoys:

- Buoy 2 – the connection between the charge converter and the hydrophone was damaged during deployment and was not able to be repaired.
- Buoy 3 – the meter for Buoy 3 spontaneously powered down and would not power back on.
- Buoy 5 – this buoy's meter was defective and isolated to the rear hydrophone plug being defective.

As a result, "reliable data" were only available from approximately 10:30 AM through approximately 11:35 AM on March 15, 2019, from three of the buoys.

4.1.4 Raw Sound Data

Raw sound and GPS data are presented below in Figure 4-3 and Figure 4-4:

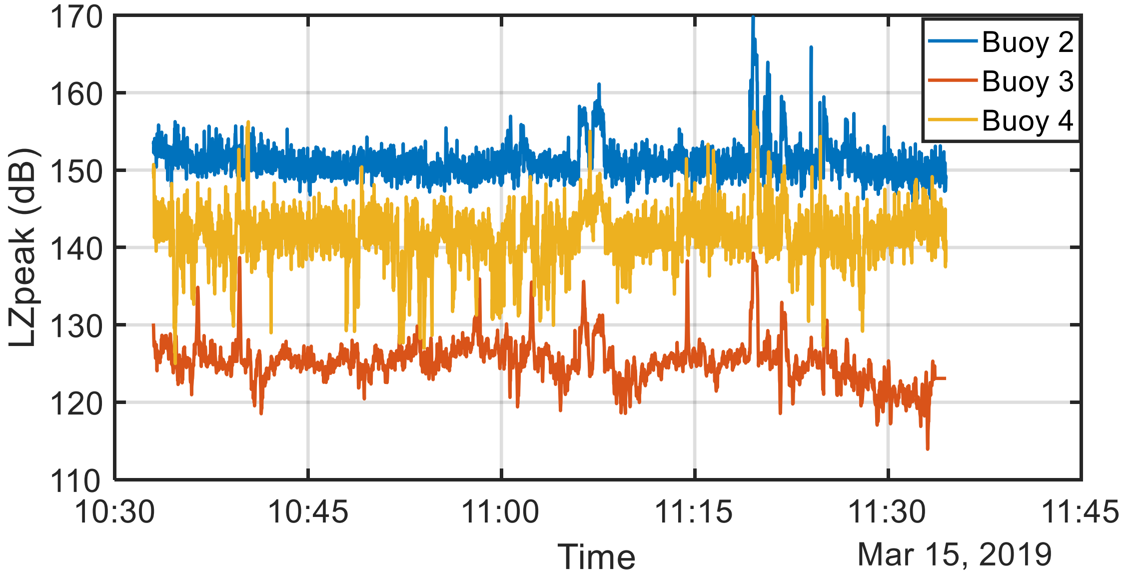


Figure 4-3. Raw sound data from Dunn's Creek

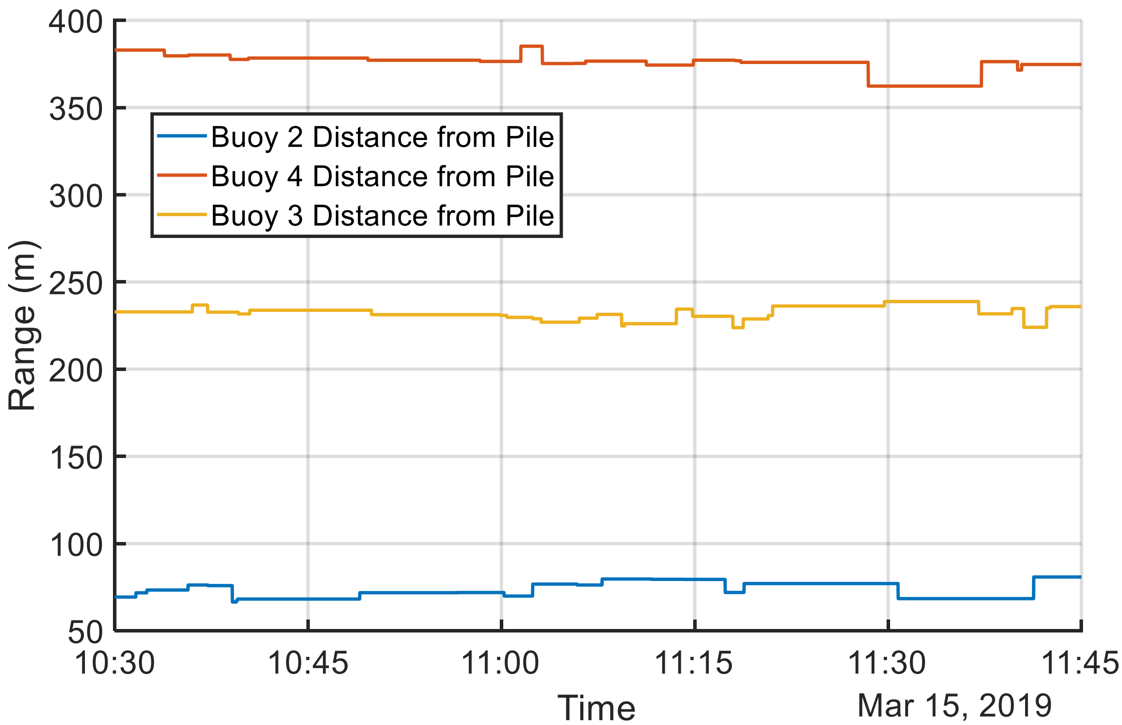


Figure 4-4. GPS data from Dunn's Creek

4.1.5 Geotechnical Data

A Model 200T Vibratory Driver was used for all sheet pile installation at Dunn’s Creek. Sheet piles consisted of 40’ lengths of 18” wide steel PZ-27 piles that were driven in pairs, for a total width of 36”. The piles were driven in 21’ of water with 15’ of embedment in the soil. Several soil-types were encountered along the bottom of the waterway. These soils were classified according to the Unified Soil Classification System (USCS) and are as follows: silty sand (SM), peat (PT), poorly graded sand (SP), poorly grades sand with silt (SP-SM), and high plasticity clay (CH). At the sheet pile location, corresponding to Borehole 12 in the boring logs located in Appendix A, the soil was classified as SP. The sheet piles were vibrated through approximately 13 feet of brown to light brown fine sand (SP) while final tip elevation rested upon gray silty fine sand with abundant shell (SM). Appendix A provides the relevant geotechnical boring logs and pile driver specifications.

4.2 Ribault River Bridge

4.2.1 Site Description

The Ribault River Bridge is located in northwest Jacksonville, Florida across Howell Drive. The field team monitored a test pile drive at the Ribault River location on May 7, 2019, and a 3-pile production pile bent on June 10, 2019. On each date, buoys were deployed in approximately the same location as indicated below in Figure 4-5:

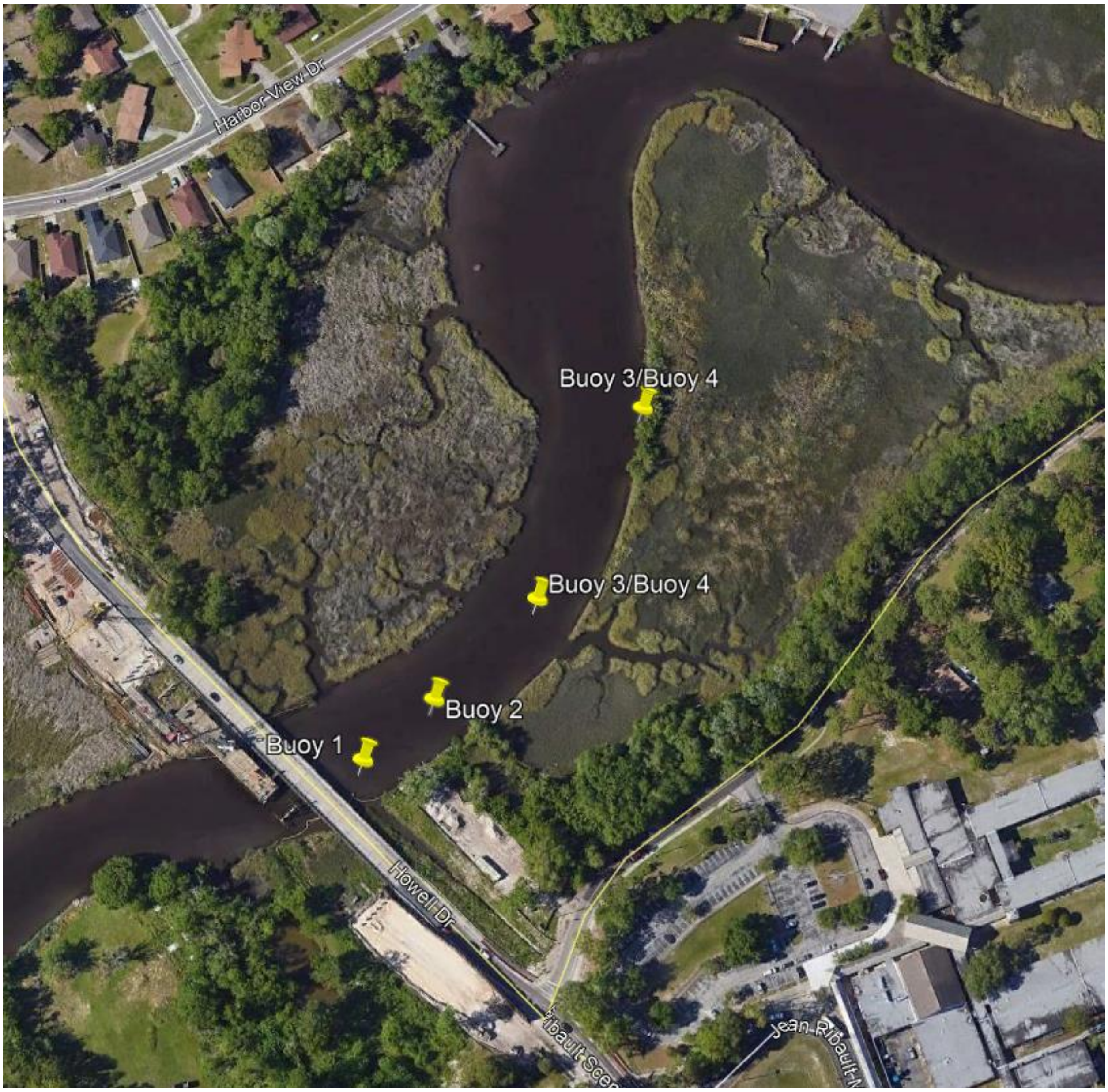


Figure 4-5. Aerial view of Ribault River Bridge with approximate buoy locations

4.2.2 Pile Driving Scope

Pile driving at the Ribault River consisted of a concrete test pile on May 7, 2019, and three concrete production piles on June 10, 2019. As shown below in Figure 4-6, all piles were driven with a percussion hammer.

Figure 4-6. Pile driving at Ribault River (May 7, 2019 test pile shown)

4.2.3 Data Collection

This site was also constrained geographically in the sense that there was insufficient width to take cross-current readings and the slight bend in the river to the north/northeast would have blocked sound travel anywhere downstream from Buoy 4. As such, the research team focused on deploying Buoy 4 as far away as possible from pile driving and then spacing intermittent buoys appropriately to yield a range of transmission loss/range data points. While approximate buoy ranges were shown in Figure 4-5, more accurate buoy ranges are presented below in Table 4-2 and Table 4-3:

Table 4-2. Buoy placement summary for Ribault River on May 7, 2019

Buoy Number	Buoy Distance (m)	Water Depth (m)	Hydrophone Depth (m)
1	24.5	3.66	1.22
2	46.5	3.66	1.22
3	202	3.05	1.22
4	106	3.05	1.22

Table 4-3. Buoy placement summary for Ribault River on June 10, 2019

Buoy Number	Buoy Distance (m)	Water Depth (m)	Hydrophone Depth (m)
1	26.5	2.35	1.22
2	50	2.19	1.22
3	107	2.10	1.22
4	199.5	2.26	1.22

Like Dunn's Creek, distances in Table 4-2 and Table 4-3 were approximated using a laser range finder. However, as with Dunn's Creek, please note that these approximate distances were reinforced with onboard GPS data that were used for analysis.

4.2.4 Raw Data

On May 7, 2019, all four functional buoys effectively recorded the drive event and associated GPS coordinates. During data analysis, LZ_{peak} data were enveloped using MATLAB's built-in "findpks" command discussed in Section 3.2. Raw data from the May 7, 2019, drive event are presented below in Figure 4-7 and Figure 4-8:

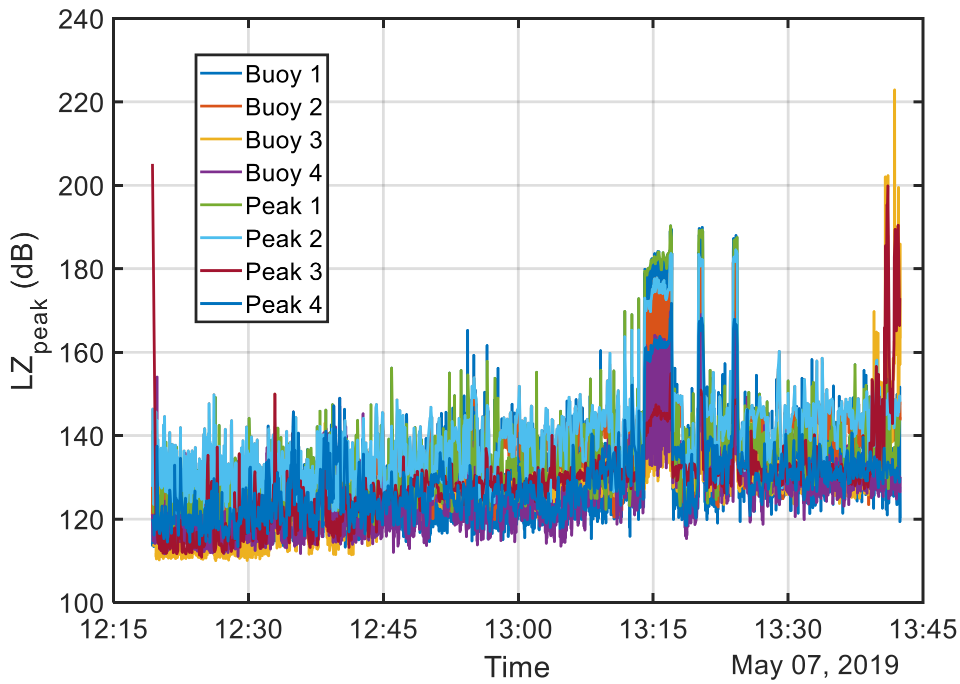


Figure 4-7. Raw data from Ribault River site during test pile driving including enveloped peaks. (Note the clear presence of the drive event occurring at approximately 13:15.)

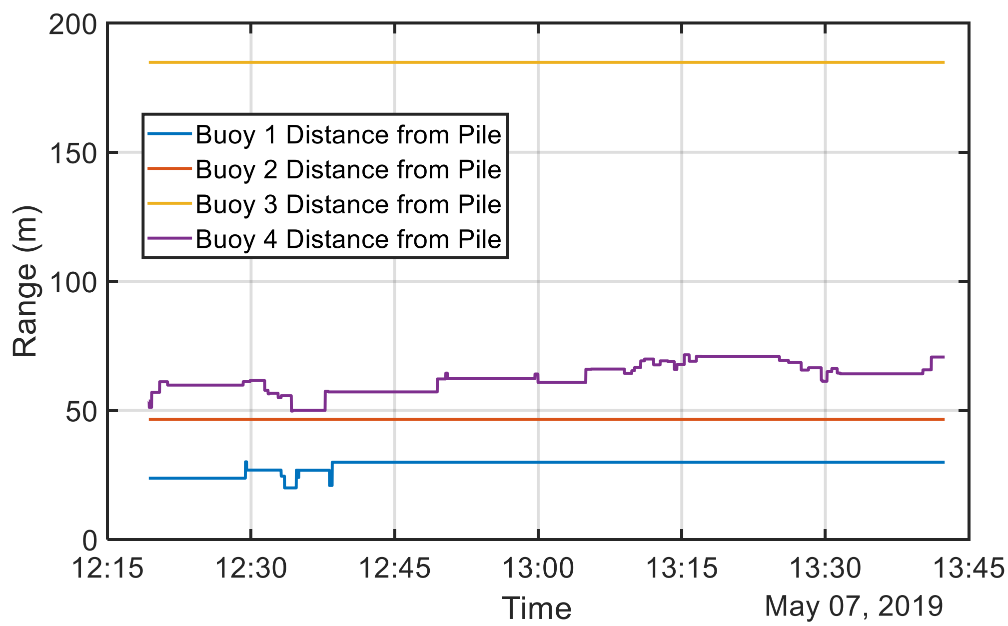


Figure 4-8. Buoy distance from pile data during test pile drive at the Ribault River site on May 7, 2019.

On June 10, 2019, two of the four GPS units malfunctioned. As such, transmission loss computations for this event should be interpreted as approximate since the laser range finding data had to be used. Raw sound data and approximate GPS data are presented below in Figure 4-9 and Figure 4-10, respectively.

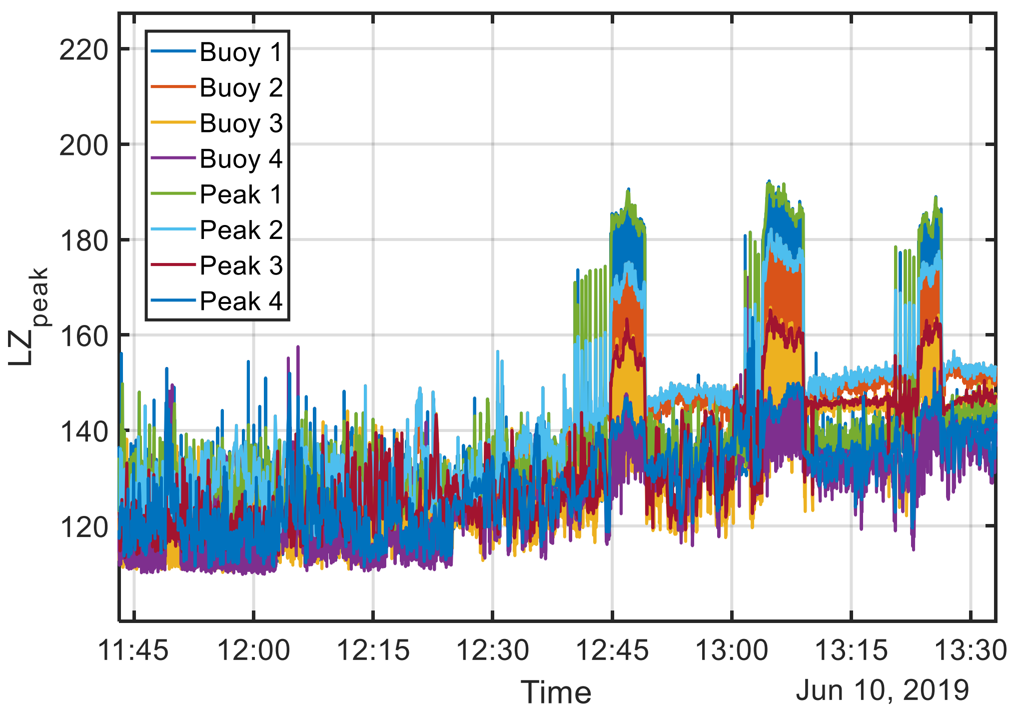


Figure 4-9. Raw sound data from Ribault River production piles. (Note the three obvious pile driving events starting at approximately 12:45.)

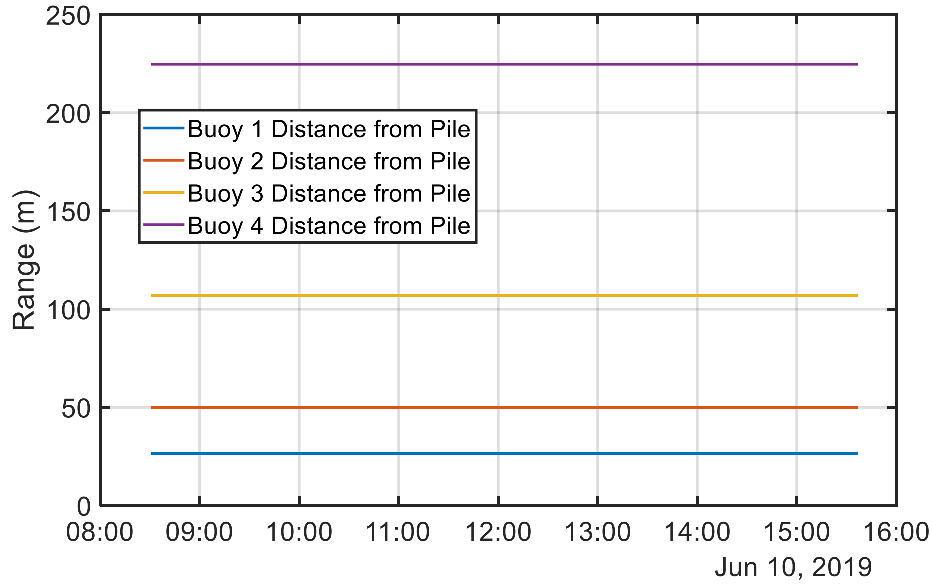


Figure 4-10. Approximate buoy locations relative to the piles during Ribault River production driving.

4.2.5 Geotechnical Data

An APE Model D36-42 hammer was used for all pile driving at the Ribault River location. Piles consisted of 24-inch square cross-section prestressed concrete piles (PCP). Throughout the pile driving, 24-inch by 24-inch by 12-inch plywood pile cushions were used. The test pile was 110-foot in length and the production piles were 60-foot in length. All piles were driven to final tip elevations of approximately -45 feet. Soil at the bottom of the waterway consisted of either peat (PT) or organic silts (OL). All piles were driven through approximately 11 feet of peat (PT), 6 feet of low plasticity silt (ML), 4 feet of PT, 2 feet of inorganic silt (MH), and approximately 5 feet of light gray sandy fossilferous limestone (see boring B-2 in PDA log in Appendix B for details). For additional details about the Ribault River location, refer to Appendix B where relevant geotechnical boring logs, pile driver specifications, pile driving logs, and test pile Pile Driving Analyzer (PDA) results are provided.

4.3 Suwannee River Bridge

4.3.1 Site Description

On April 18, 2019, the research team traveled to the Suwannee River Bridge near Dowling Park, Florida across SR 250. Site location is shown below in Figure 4-11 along with approximate buoy location:

Figure 4-11. Aerial view of the Suwannee River Bridge with approximate buoy locations

4.3.2 Pile Driving Scope

Driving at the Suwannee River consisted of percussion driving three steel trestle piles as shown below in Figure 4-12.

Figure 4-12. Steel trestle piles driven at Suwannee River Bridge

4.3.3 Data Collection

This site was constrained geographically in the cross-current direction, but provided significant space for the buoys in the down-current direction. Approximate buoy placement distances, water depths, and hydrophone depths are summarized below in Table 4-4:

Table 4-4. Buoy placement summary for Suwannee River Bridge

Buoy Number	Buoy Distance (m)	Water Depth (m)	Hydrophone Depth (m)
2	15	4.88	2.44
3	65	3.96	2.44
4	502	2.74	1.52

Due to issues with two of the hydrophone while on site, data were only collected from the three functional buoys. In addition, the GPS trackers produced anomalous readings and therefore, rangefinder data were used for analysis.

4.3.4 Raw Data

The raw sound data produced a very "clean" signal as shown below in Figure 4-13. Approximate range data are presented below in Figure 4-14.

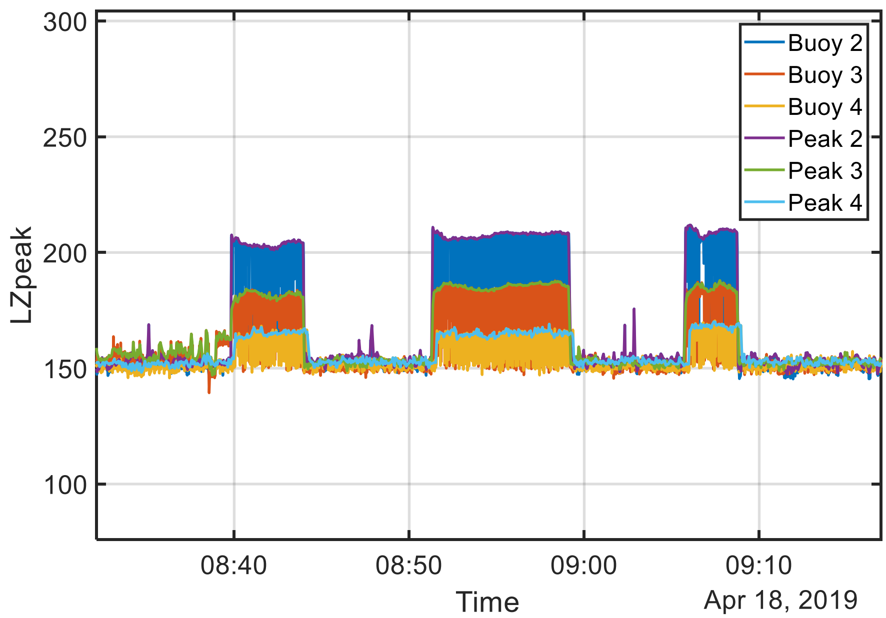


Figure 4-13. Raw sound data from Suwannee River Bridge

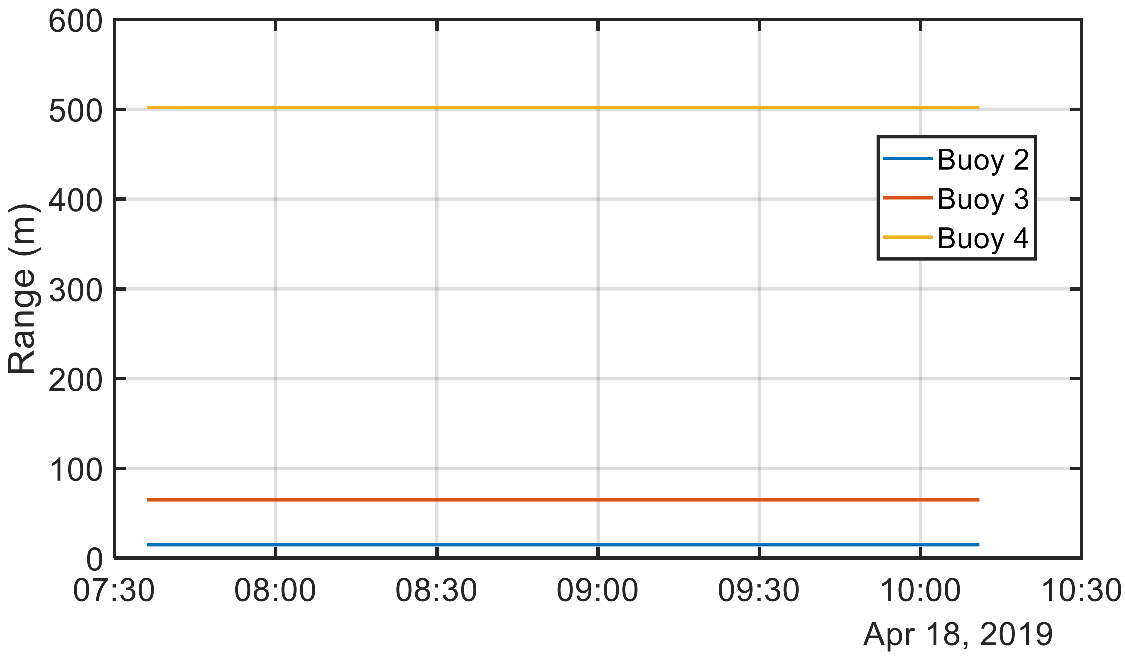


Figure 4-14. Approximate range data from the Suwannee River Bridge.

4.3.5 Geotechnical Data

A Del-Mag Model D-46 Impact Driver was used for all trestle pile driving at the Suwannee River location. Piles consisted of 24-inch diameter by 60-foot long open-ended steel piles that were driven to a final tip elevation of approximately -50-feet. At the bottom of the waterway, fine to medium sand (SP) with some sand to fine gravel-sized limestone, granite and other rocks (fill) was encountered. The piles were driven through various limestone layers until their tips rested upon light gray to gray fine to medium-grained fossiliferous limestone (see boring B-4 in Appendix C for details). For additional details about the Suwanee River location, refer to Appendix C where a relevant geotechnical boring sample and pile driver specifications are provided.

4.4 Bayway E Bridge

4.4.1 Site Description

On June 3 and 4, 2019, the field team visited the Bayway E Bridge in St. Petersburg, Florida. The site location is shown below in Figure 4-15 as well as approximate buoy locations:

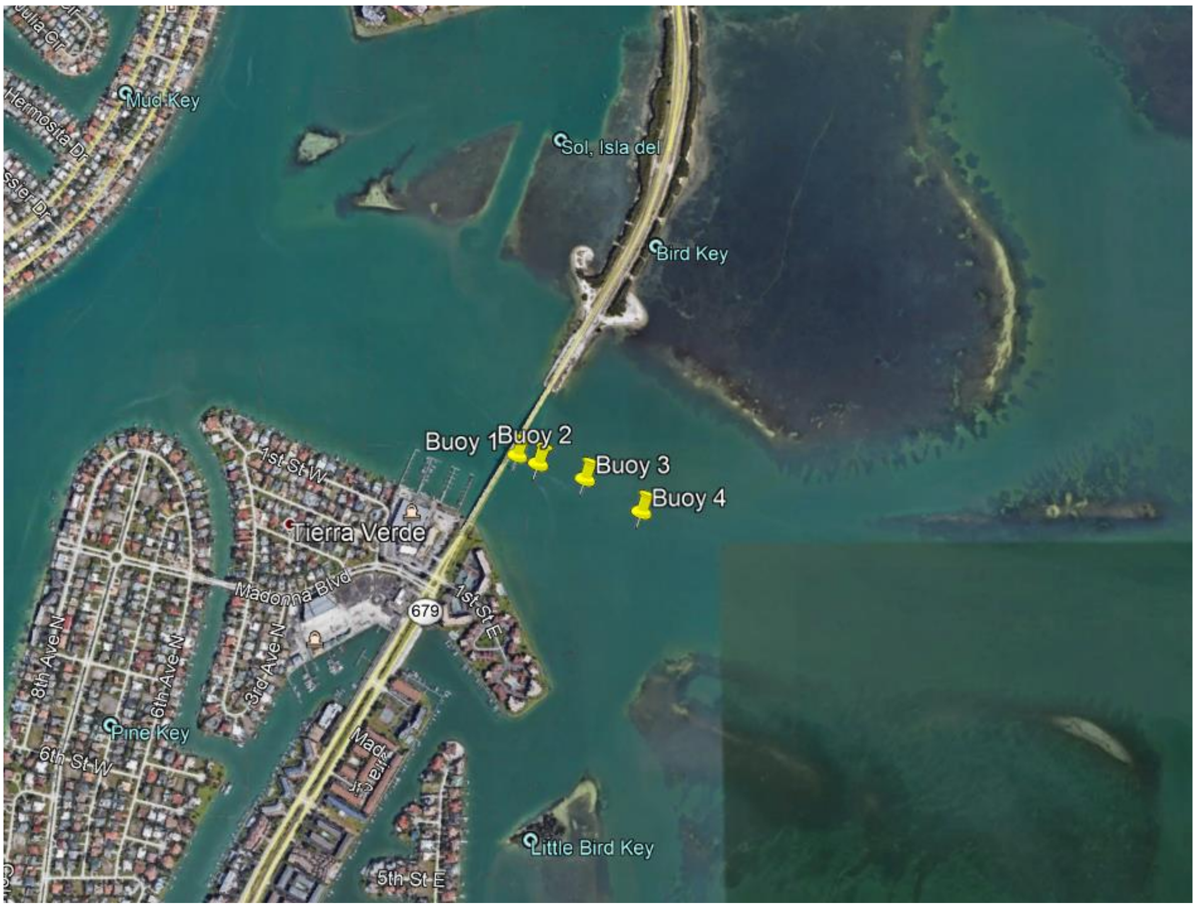


Figure 4-15. Aerial view of the Bayway E Bridge with approximate buoy locations.

4.4.2 Scope of Pile Driving

Driving consisted of the installation of three steel piles on June 3, 2019, and one steel pile on June 4, 2019, using a vibratory hammer as shown below in Figure 4-16. The piles were 'set' with the vibratory hammer in preparation for impact driving. Due to construction delays, no impact driving was performed as scheduled during this testing. Only the June 4, 2019, data from approximately 0830 through 1000 produced sufficient sound transmission for analysis, but this recording was very close to ambient sound conditions.

Figure 4-16. Pile driving at Bayway E Bridge on June 4, 2019.

4.4.3 Data Collection

Due to the limited pile driving scope from June 3 and 4, 2019, investigators focused data collection in the down-current direction. A summary table showing buoy placement is shown below in Table 4-5:

Table 4-5. Buoy placement summary for Bayway E. Bridge

Buoy Number	Buoy Distance (m)	Water Depth (m)	Hydrophone Depth (m)
1	16-25 distance to pile 1 and to pile 4	3.05	1.52
2	73	3.96	1.83
3	177	3.66	1.83
4	370	2.96	1.83

Four of the five meters were usable throughout the driving procedure. Investigators noted that driving was relatively quiet throughout and expected relatively low noise-level readings. There were no noted issues with data collection from the meters at this site. However, two of the four GPS units produced anomalous data. As such, rangefinder data were used for these buoys.

4.4.4 Raw Data

Raw data with enveloped peaks from the 0830-1000 drive events are presented below in Figure 4-17 and Figure 4-18:

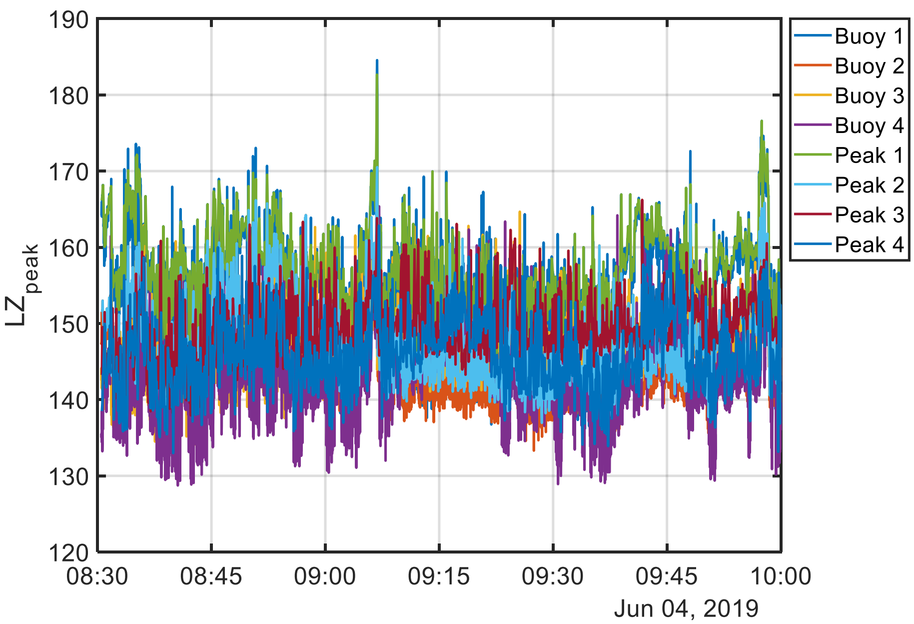


Figure 4-17. Raw data with enveloped peaks from Bayway E Bridge.

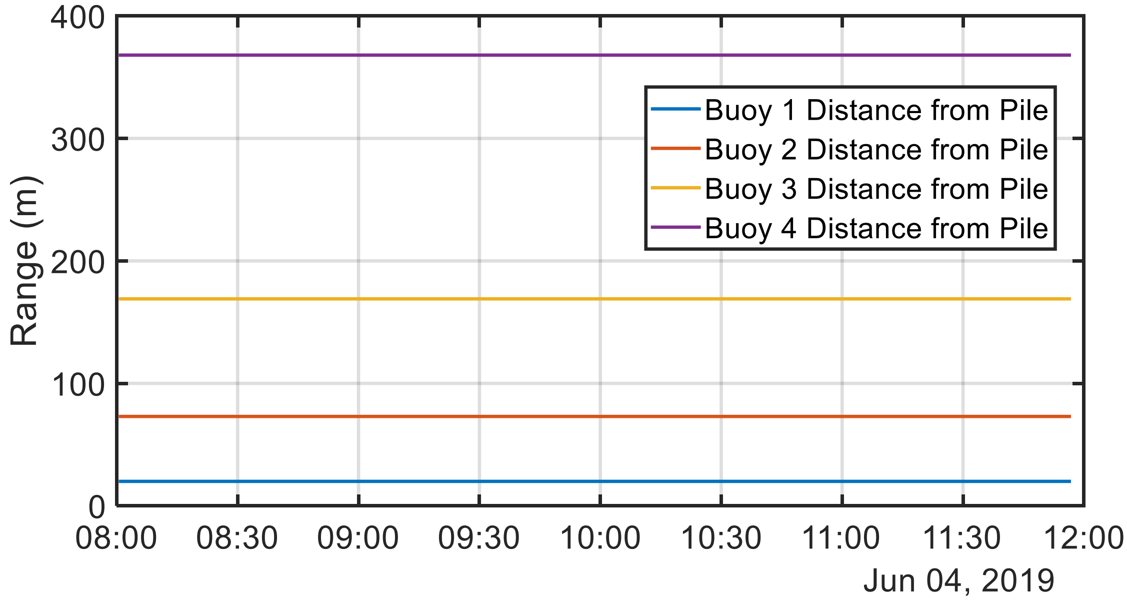


Figure 4-18. Approximate range data from Bayway E Bridge

4.4.5 Geotechnical Data

A Model 200T Vibratory Driver was used for all trestle pile driving at the Bayway E River location. Piles consisted of 36-inch diameter by 85-foot long open-ended steel piles. All piles were driven to a final tip elevation of approximately -83.6-foot. Soil at the bottom of the waterway consisted of SP/SP-SM (Boring B-10 in Appendix E). Piles were vibrated through the 5-foot SP/SP-SM layer, a 6-foot SM layer, another 2-foot SP/SP-SM layer; a 5-foot SC layer, a 6-foot SM layer, a 10-foot SP/SP-SM layer, a 5-foot SM layer, a 6-foot SP/SP-SM layer, and finally rested upon a large (24-foot thick) SM layer. For additional details about the Bayway E River location, refer to Appendix D where relevant geotechnical boring logs and pile driver specifications are provided.

4.5 John Sims Parkway Bridge

4.5.1 Site Description

From June 23 through June 25, 2019, the field team visited the John Sims Parkway Bridge in Niceville, Florida. Site location map and approximate buoy locations are shown below in Figure 4-19:

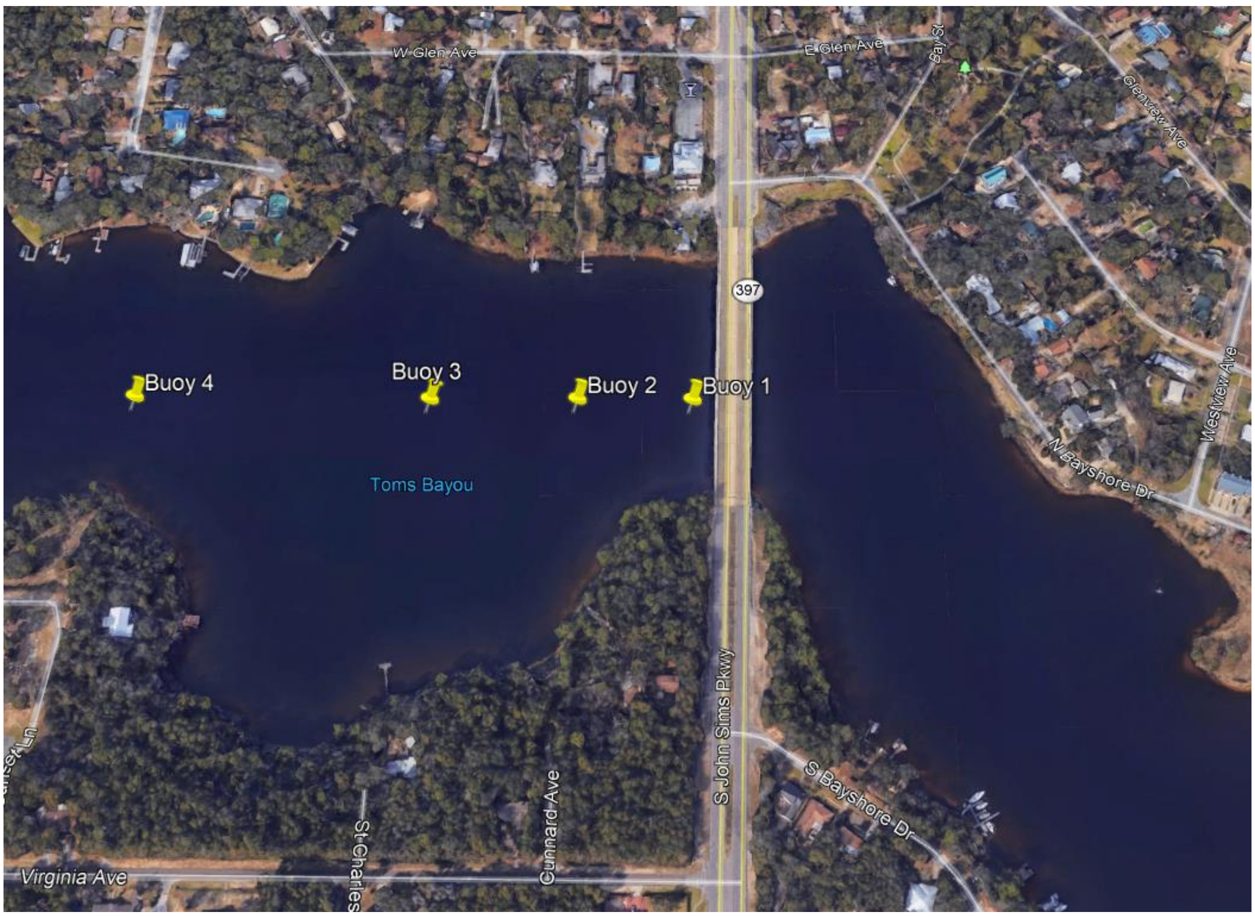


Figure 4-19. Aerial view of John Sims Parkway Bridge with approximate buoy locations

4.5.2 Scope of Pile Driving

Driving at the John Sims Parkway consisted of driving one pile per day, moving the template in one day, and driving another pile the next day. The first day of driving occurred on June 24, 2019, as scheduled. The template move occurred on June 25, 2019, but there was an issue with the move. As such, driving was cancelled for June 26, 2019, and the field team returned to UNF. The construction barge is shown below in Figure 4-20.

Figure 4-20. Concrete pile being placed into position at John Sims Parkway Bridge

4.5.3 Data Collection

Due to the limited pile driving expected on the travel dates, investigators focused on sound propagation in the down-current direction. A summary of buoy locations is presented below in Table 4-6:

Table 4-6. Buoy placement summary for John Sims Parkway

Buoy Number	Buoy Distance (m)	Water Depth (m)	Hydrophone Depth (m)
1	22.5	3.96	1.83
2	69	3.96	1.83
3	174.5	3.66	1.83
4	377	3.66	1.83

Four of the five meters were usable throughout the driving. All four GPS units also functioned properly during driving.

4.5.4 Raw Data

Raw sound data from the John Sims Parkway is presented below in Figure 6-21 while GPS data are presented in Figure 4-22:

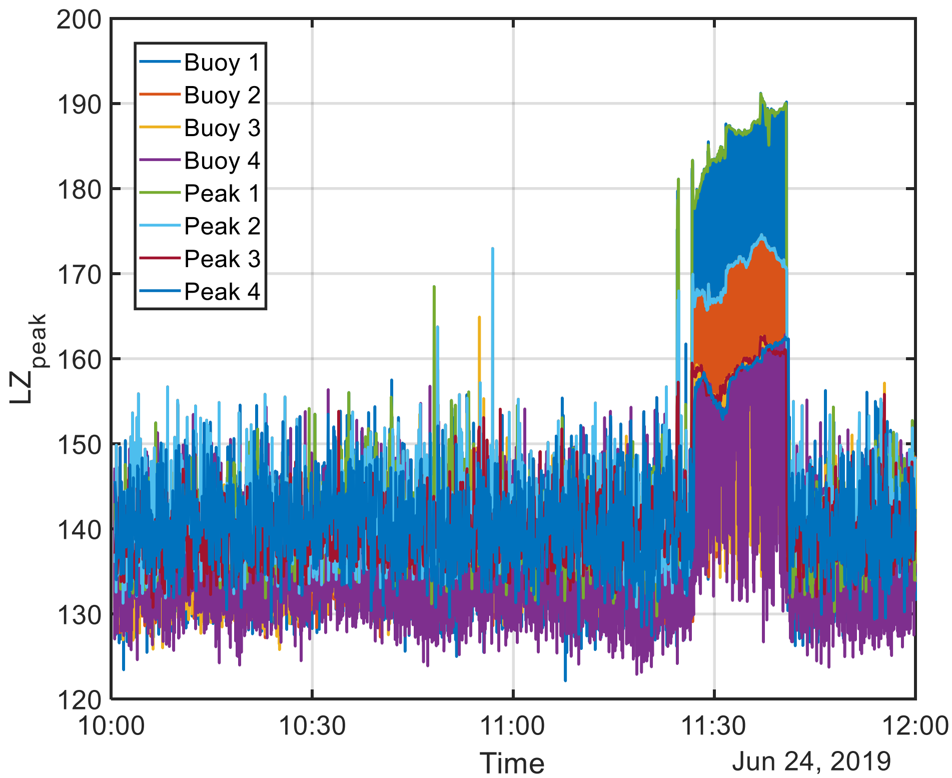


Figure 4-21. Raw sound data from John Sims Parkway

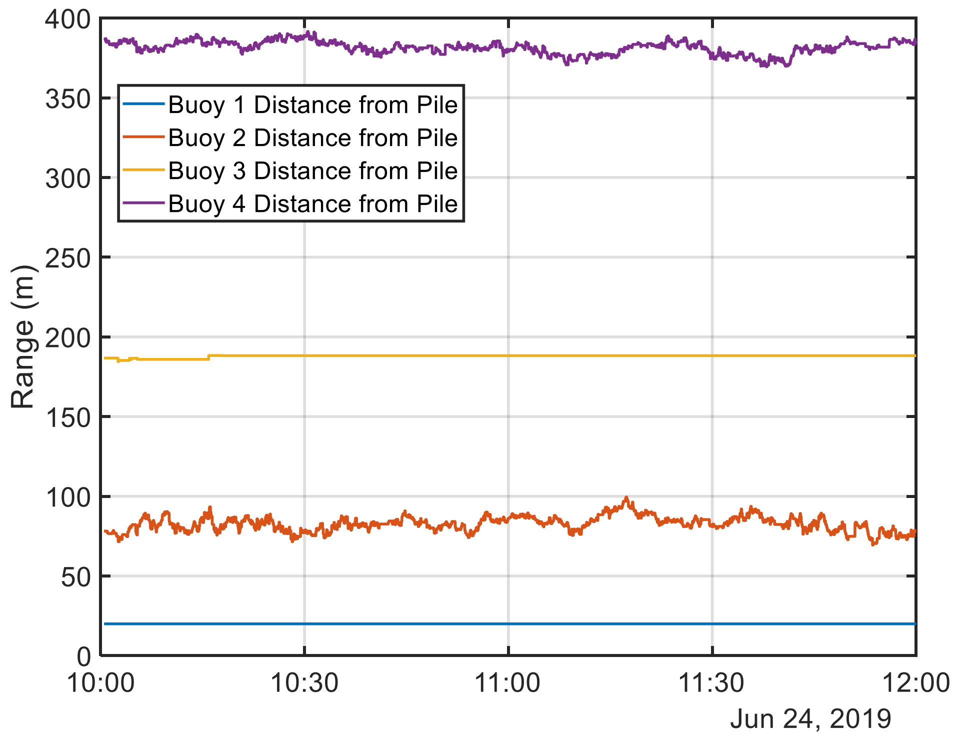


Figure 4-22. Approximate range data from John Sims Parkway

4.5.5 Geotechnical Data

A BSP CX85-u Impact Driver was used for all pile driving at the John Sims Parkway location. The pile consisted of 18-inch by 18-inch square cross-section PCP. Throughout driving 18-inch by 18-inch by 8.5-inch plywood pile cushions were used. The pile was 81-foot in length and driven to a final tip elevation of approximately -61.1-foot. Soil at the bottom of the waterway consisted of gray to dark gray organic silty sand to peat occasionally with shells (PT/SM). The pile was driven through the 14-foot PT/SM layer, a 16-foot SP/SP-SM layer, a 1-foot SC/CL layer, a 2-foot SP/SP-SM layer, a 29-foot SM/SM-SC layer, a SP/SP-SM layer, and rested upon a SM/SM-SC layer. For additional details about the John Sims Parkway location, refer to Appendix E where relevant geotechnical boring logs, pile driver specifications, and pile driving logs are provided.

Chapter 5: Data Analysis

This chapter provides the data analysis for each of the site locations tested. The tabular data as well as the best fit regressions lines and ultimately the average recorded *F* values are provided.

5.1 Dunn's Creek Bridge

Tabular data from the Dunn's Creek Bridge sheet pile vibrating are presented below in Table 5-1 and Table 5-2. Best-fit regression curves are shown below in Figure 5-1 and Figure 5-3. In addition, the isolated noise signal from this drive event is shown in Figure 5-2 and Figure 5-4:

Table 5-1. Numerical Data Summary for Dunn's Creek First Sheet Pile Drive

Buoy Name	**RMS_{90} (dB)**	**$Peak_{90}$ (dB)**	**SEL_{90} (dB)**	**Peak(dB)**	**SEL_{cum} (dB)**
Buoy 2	155.89	162.37	177.31	169.81	180.16
Buoy 3	129.60	128.56	150.24	139.27	152.82
Buoy 4	145.73	138.54	166.96	155.76	169.53
At Pile (from best-fit curve)	**224**	**255**	**248**	**250**	**251**
				Transmission Loss Coefficient, *F* =	**37**

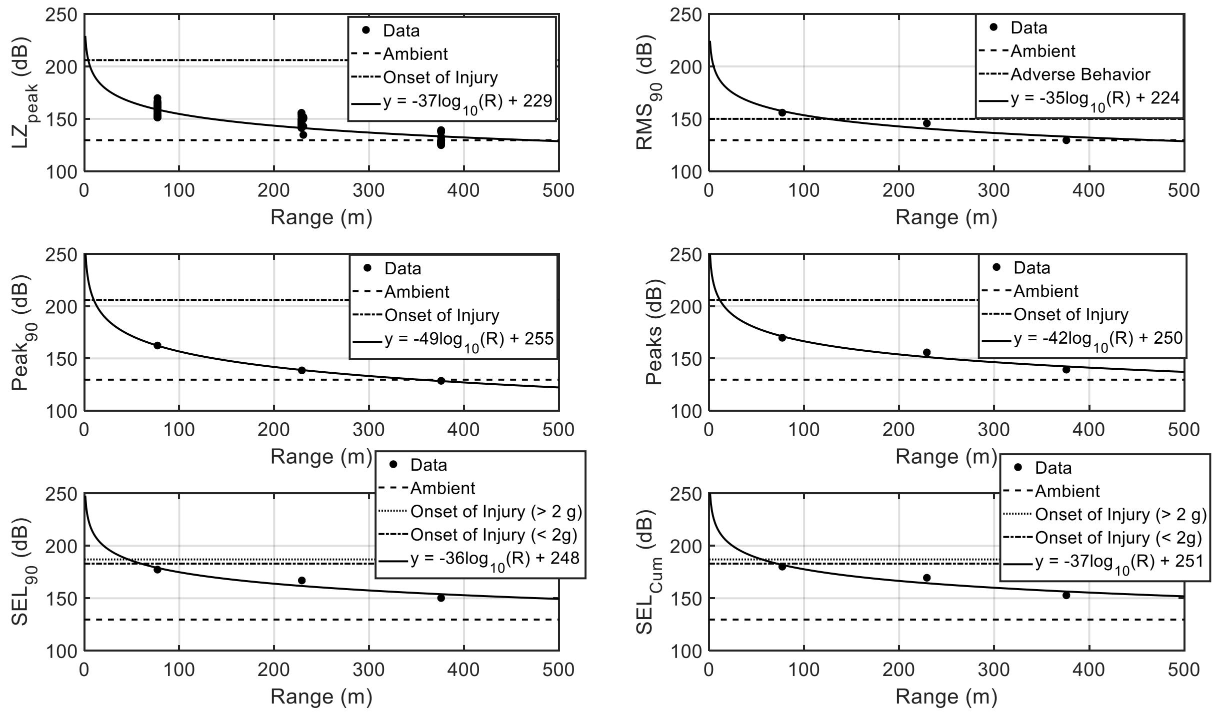


Figure 5-1. Best-fit regression curves from Dunn's Creek first pile drive showing fit with all data (top-left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right)

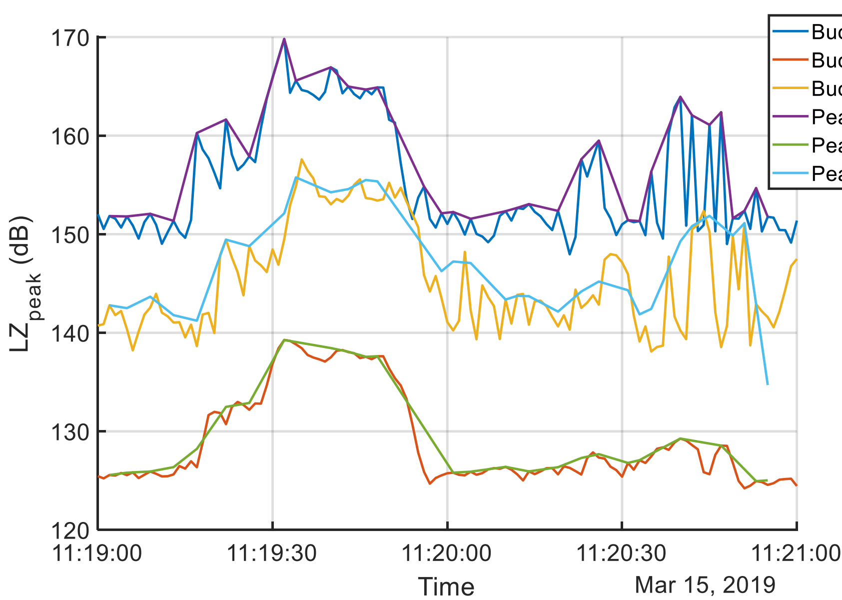


Figure 5-2. Isolated sound data from Dunn's Creek first sheet pile drive

Table 5-2. Numerical Data Summary for Dunn's Creek second Sheet Pile Drive

Buoy Name	**RMS_{90} (dB)**	**$Peak_{90}$ (dB)**	**SEL_{90} (dB)**	**Peak(dB)**	**SEL_{cum} (dB)**
Buoy 2	155.19	152.41	176.36	161.13	177.40
Buoy 3	128.35	124.69	149.29	134.63	150.71
Buoy 4	145.03	142.47	165.78	153.64	167.24
At Pile (from best-fit curve)	**225**	**224**	**246**	**229**	**247**
Transmission Loss Coefficient, *F* =					**36**

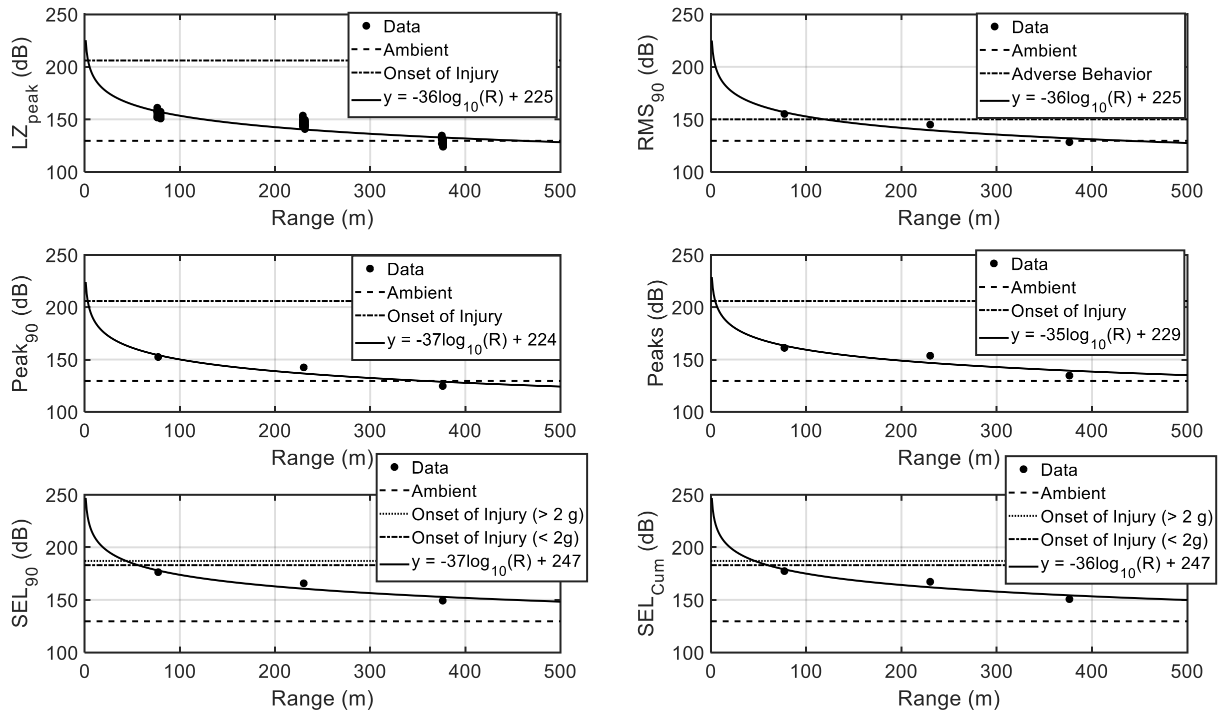


Figure 5-3. Best-fit regression curves from Dunn's Creek second pile drive showing fit with all data (top-left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right)

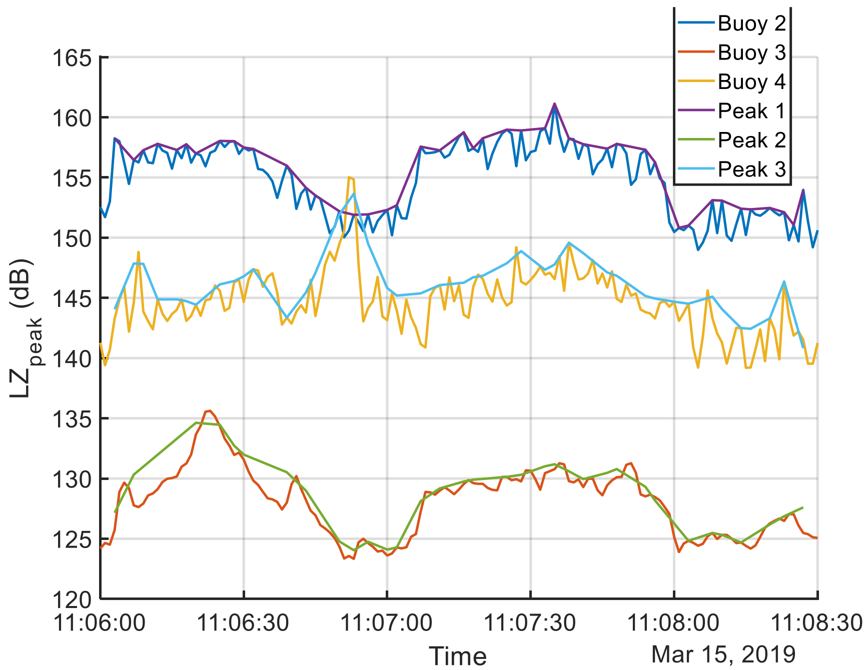


Figure 5-4. Isolated sound data from Dunn's Creek second sheet pile drive

The data recorded at Dunn's Creek were very consistent for each drive event. Through the use the best fit regression curves, an average *F*-value of 36.5 was calculated between the two pile driving events.

5.2 Ribault River Bridge

5.2.1 Test Pile

Tabular data from the Ribault River Test Piles are presented below in Table 5-3 while best-fit regression curves are shown below in Figure 5-5 and the isolated sound signal is presented in Figure 5-6:

Table 5-3. Numerical Data Summary for Ribault River Test Pile

Buoy Name	RMS_{90} (dB)	$Peak_{90}$ (dB)	SEL_{90} (dB)	Peak(dB)	SEL_{cum} (dB)
Buoy 1	173.85	183.49	201.44	190.31	203.42
Buoy 2	168.52	172.51	194.33	183.66	196.62
Buoy 3	141.00	137.01	164.58	154.88	167.23
Buoy 4	153.12	161.69	180.45	169.60	181.74
At Pile (from best-fit curve)	**237**	**271**	**272**	**258**	**272**
				Transmission Loss Coefficient, *F* =	**48**

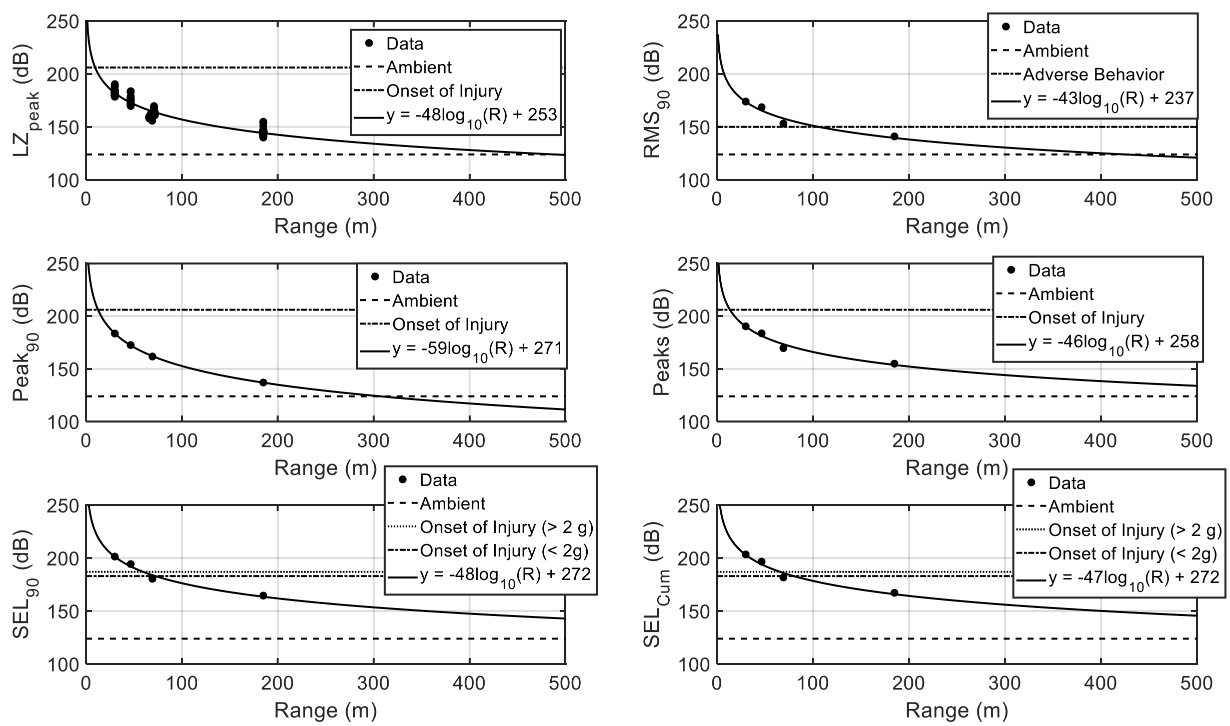


Figure 5-5. Best fit regression curves from the Ribault River Test Pile showing fit with all data (top left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right).

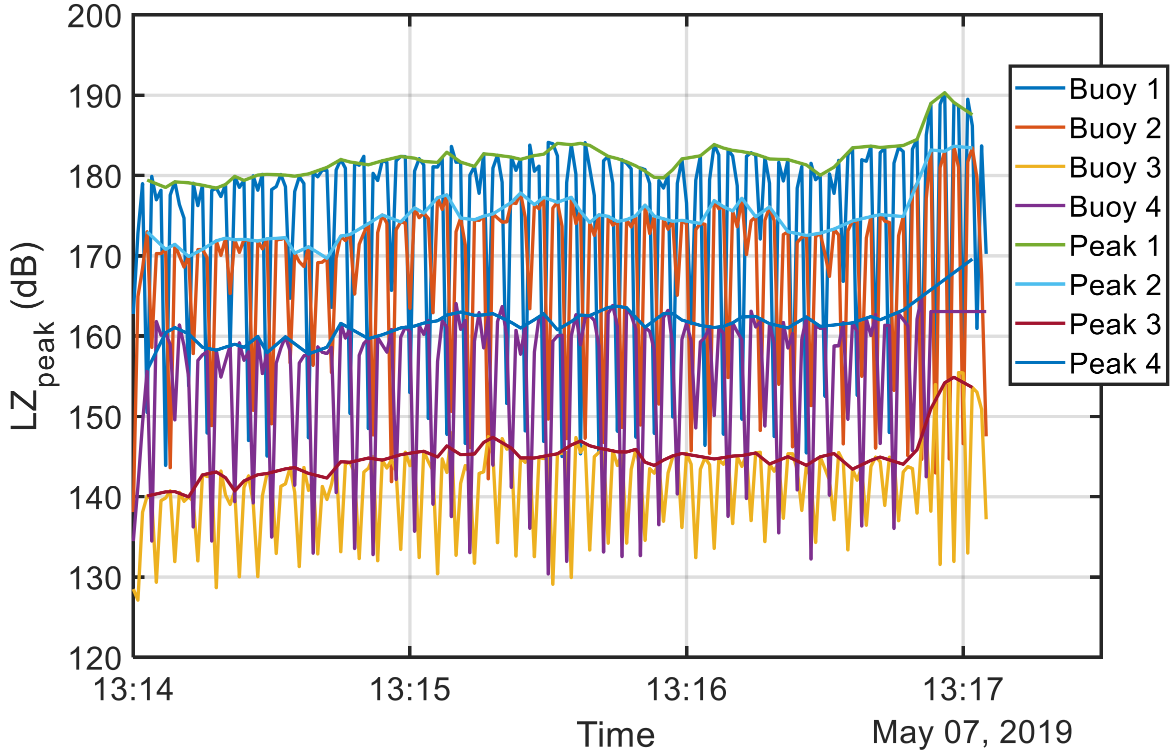


Figure 5-6. Isolated sound data from Ribault River test pile drive

Through the use the best fit regression curves and present in Table 7-3, the calculated *F* is approximately 48 for this pile.

5.2.2 Production Piles

Three production piles were driven on June 10, 2019. Analysis for each of these drive events is presented below from Table 5-4 through Table 5-6 and from Figure 5-7 through Figure 5-12:

Table 5-4. Numerical Data Summary for Ribault River Production Pile 1

Buoy Name	RMS_{90} (dB)	$Peak_{90}$ (dB)	SEL_{90} (dB)	Peak(dB)	SEL_{cum} (dB)
Buoy 1	173.96	148.35	205.28	190.14	206.89
Buoy 2	163.38	167.20	191.36	175.28	193.05
Buoy 3	149.45	129.73	177.01	163.40	178.92
Buoy 4	136.74	138.43	162.56	154.12	164.41
At Pile (from best-fit curve)	**237**	**175**	**271**	**244**	**272**
				Transmission Loss Coefficient, *F* =	**46**

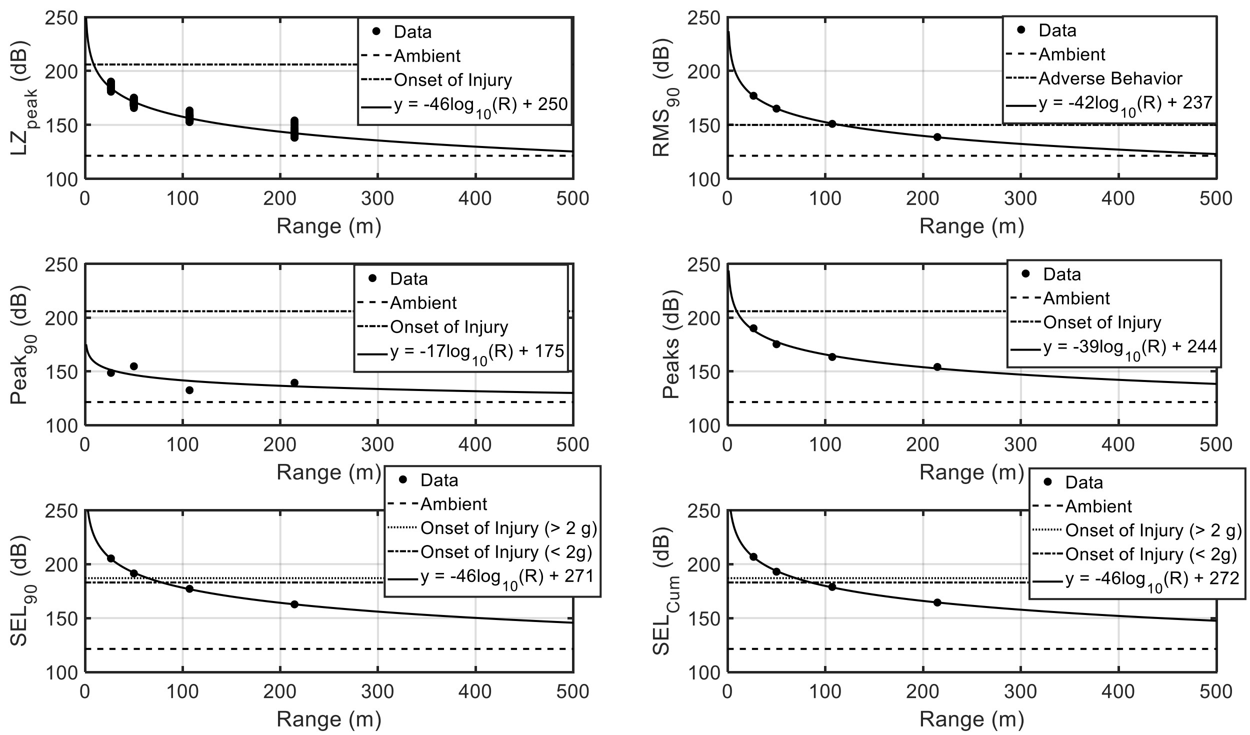


Figure 5-7. Best-fit regression curves from Ribault River Production Pile 1 showing fit with all data (top-left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right)

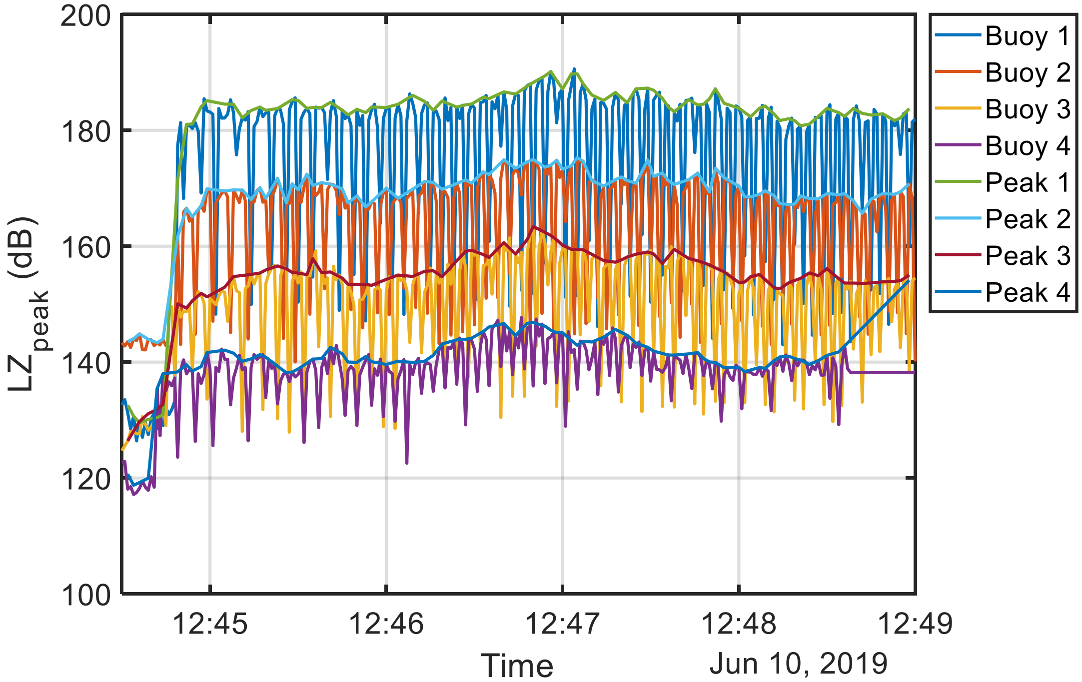


Figure 5-8. Isolated sound data from Ribault River production pile 1.

Table 5-5. Numerical Data Summary for Ribault River Production Pile 2

Buoy Name	**RMS_{90} (dB)**	**$Peak_{90}$ (dB)**	**SEL_{90} (dB)**	**Peak(dB)**	**SEL_{cum} (dB)**
Buoy 1	180.14	188.01	209.09	191.80	210.56
Buoy 2	170.56	177.35	198.41	182.21	199.84
Buoy 3	156.48	158.36	182.18	165.28	183.52
Buoy 4	142.97	140.99	167.76	151.30	169.08
At Pile (from best-fit curve)	**240**	**264**	**275**	**258**	**277**
				Transmission Loss Coefficient, *F* =	**46**

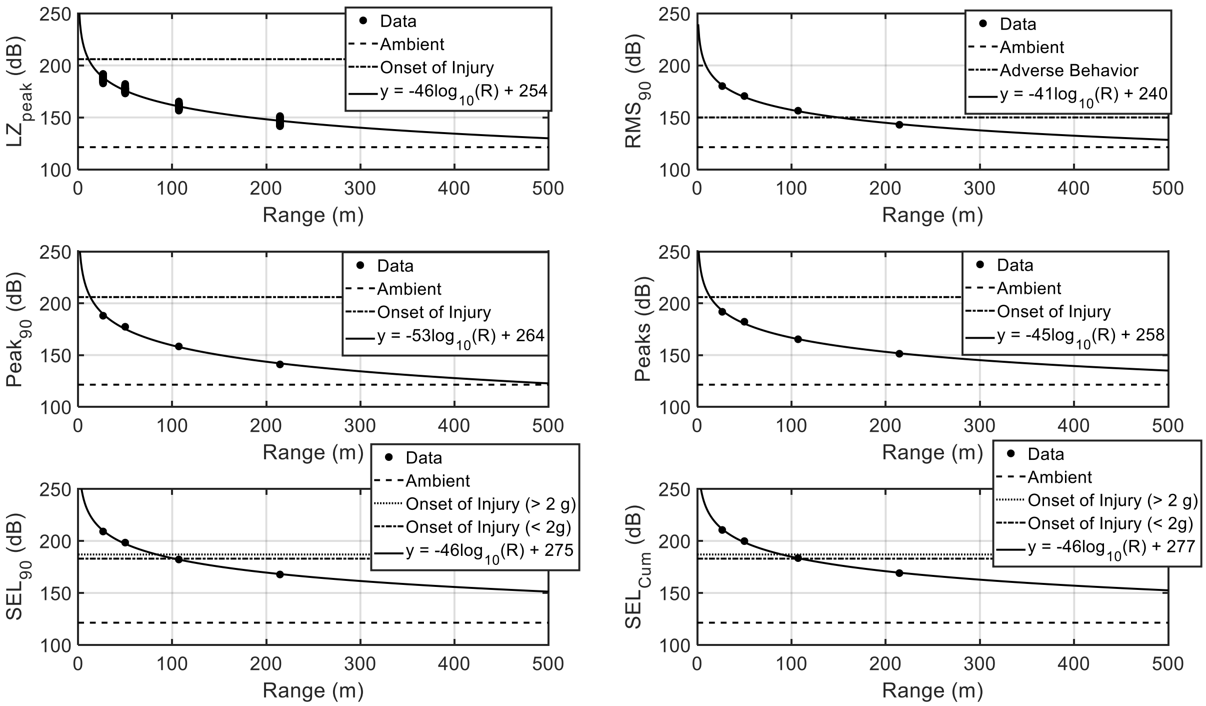


Figure 5-9. Best-fit regression curves from Ribault River Production Pile 2 showing fit with all data (top-left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right)

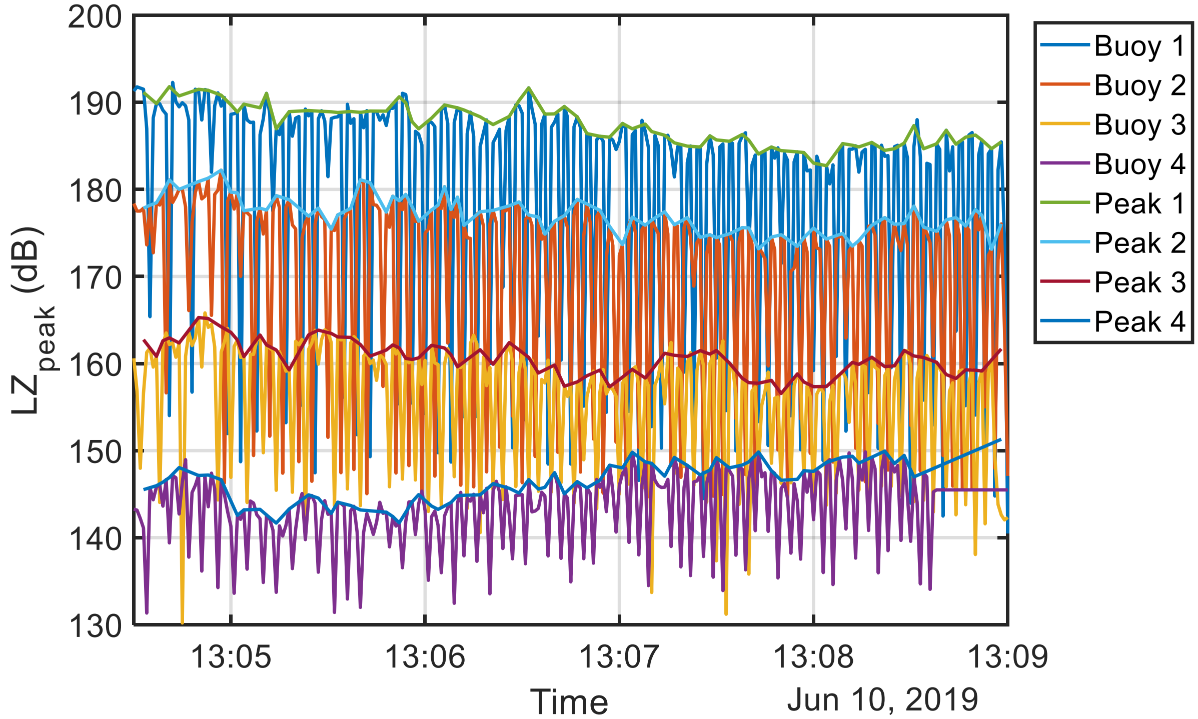


Figure 5-10. Isolated sound data from Ribault River production pile 2.

Table 5-6. Numerical Data Summary for Ribault River Production Pile 3

Buoy Name	RMS_{90} (dB)	$Peak_{90}$ (dB)	SEL_{90} (dB)	Peak(dB)	SEL_{cum} (dB)
Buoy 1	175.56	142.30	203.05	188.81	204.59
Buoy 2	167.36	149.84	192.54	177.55	193.98
Buoy 3	154.89	144.02	178.95	163.60	180.52
Buoy 4	140.84	143.54	164.07	152.02	165.98
At Pile (from best-fit curve)	**234**	**257**	**266**	**217**	**267**
				Transmission Loss Coefficient, *F* =	**41**

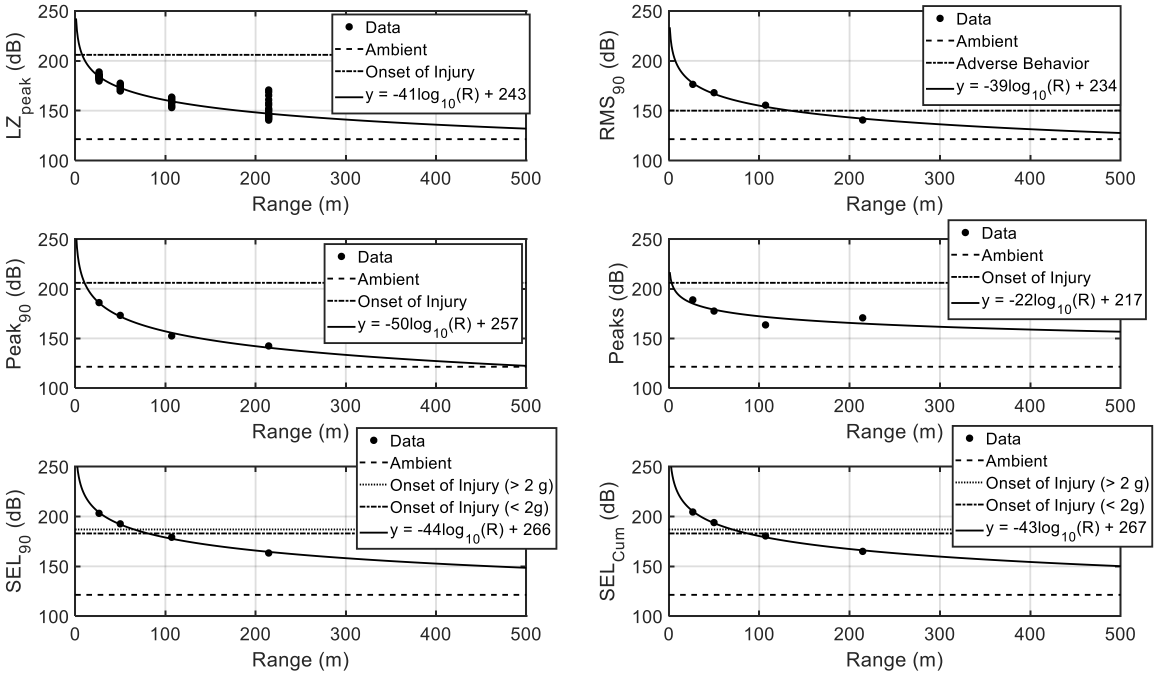


Figure 5-11. Best-fit regression curves from Ribault River Production Pile 3 showing fit with all data (top-left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right)

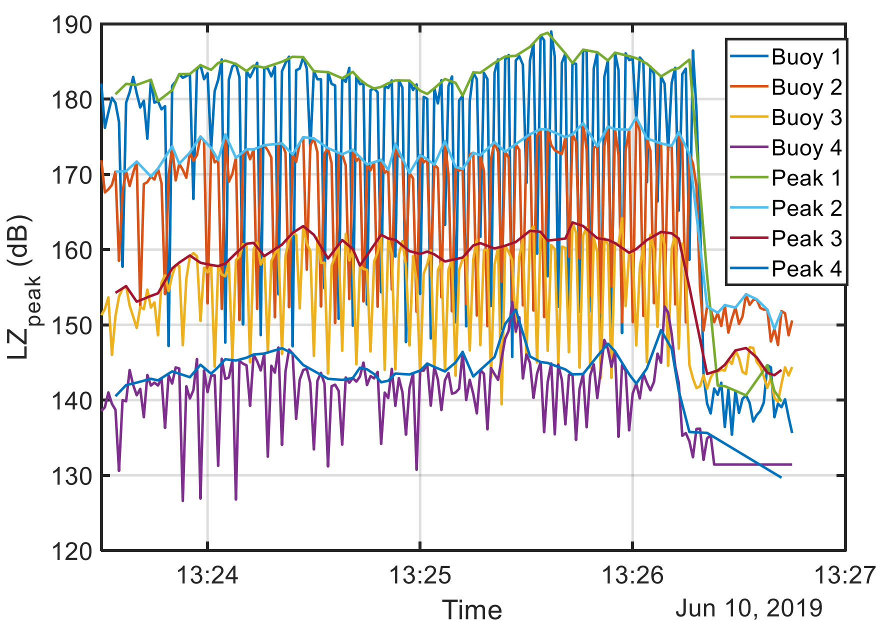


Figure 5-12. Isolated sound data from Ribault River production pile 3.

As shown in the tables and figures above, the *F*-values for the production piles varied between 46 and 41, with an average *F* of 44.3. These valves appear to compare well with the *F*-value measured using the test pile data which produced an *F-value* of 48.

5.3 Suwannee River Bridge

Tabular data from the Suwannee River Bridge are presented below from Table 7-7 through Table 5-8 while best-fit regression curves are shown below from Figure 7-13 through Figure 5-18:

Table 5-7. Numerical Data Summary for Suwannee River Bridge Pile 1

Buoy Name	RMS_{90} (dB)	$Peak_{90}$ (dB)	SEL_{90} (dB)	Peak(dB)	SEL_{cum} (dB)
Buoy 2	197.85	204.18	225.44	206.40	226.41
Buoy 3	185.49	189.38	211.58	185.89	212.55
Buoy 4	161.90	165.48	186.29	172.87	187.30
At Pile (from best-fit curve)	**227**	**235**	**257**	**229**	**258**
				Transmission Loss Coefficient, *F* =	**25**

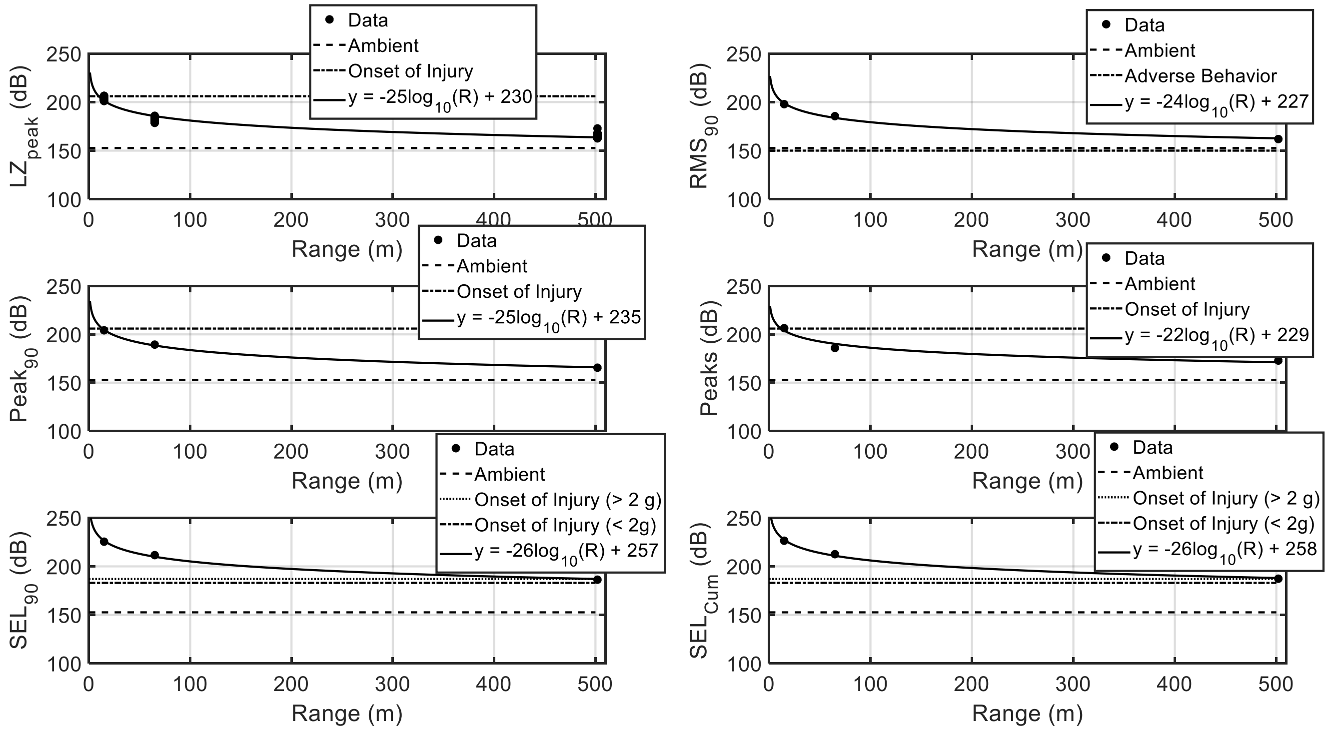


Figure 5-13. Best-fit regression curves from Suwannee River Bridge Pile 1 showing fit with all data (top-left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right)

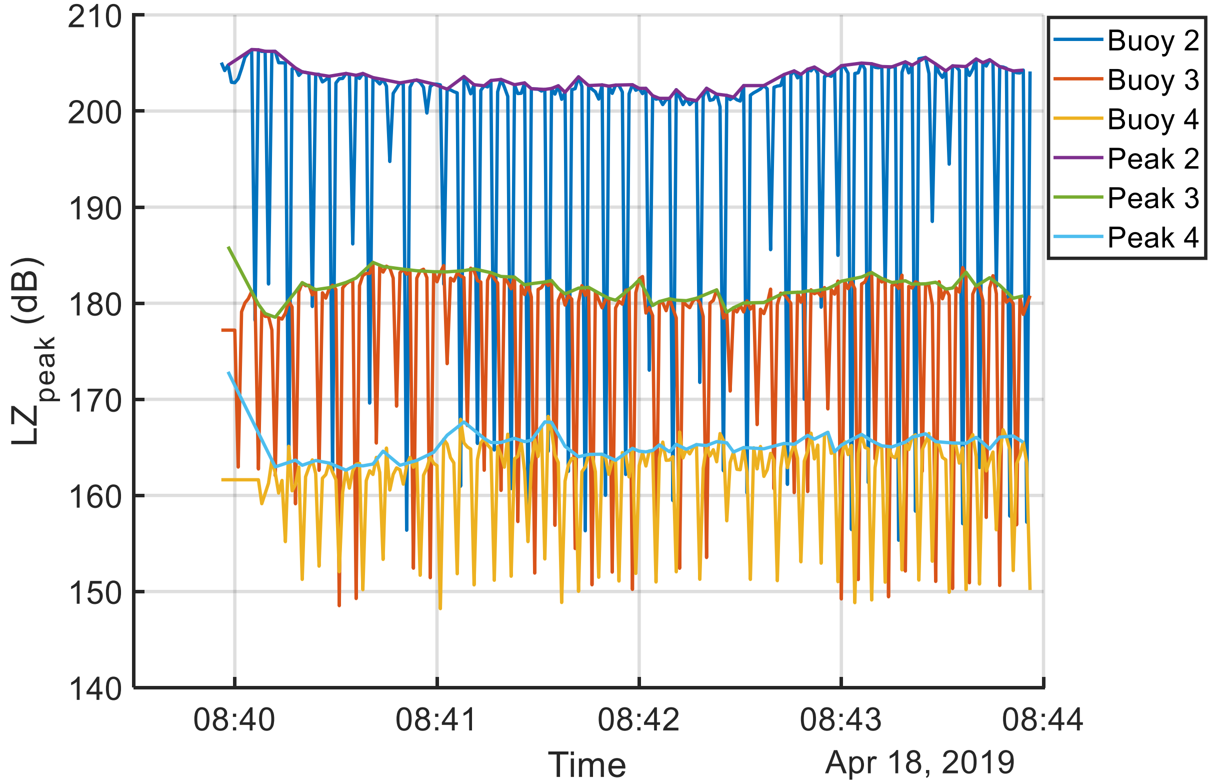


Figure 5-14. Isolated sound data from Suwannee River pile 1

Table 5-8. Numerical Data Summary for Suwannee River Bridge Pile 2

Buoy Name	RMS_{90} (dB)	$Peak_{90}$ (dB)	SEL_{90} (dB)	Peak(dB)	SEL_{cum} (dB)
Buoy 2	199.05	208.45	231.93	209.38	232.79
Buoy 3	187.09	187.29	218.01	187.59	218.94
Buoy 4	161.59	164.97	188.96	169.09	189.99
At Pile (from best-fit curve)	**230**	**241**	**267**	**238**	**268**
				Transmission Loss Coefficient, *F* =	**28**

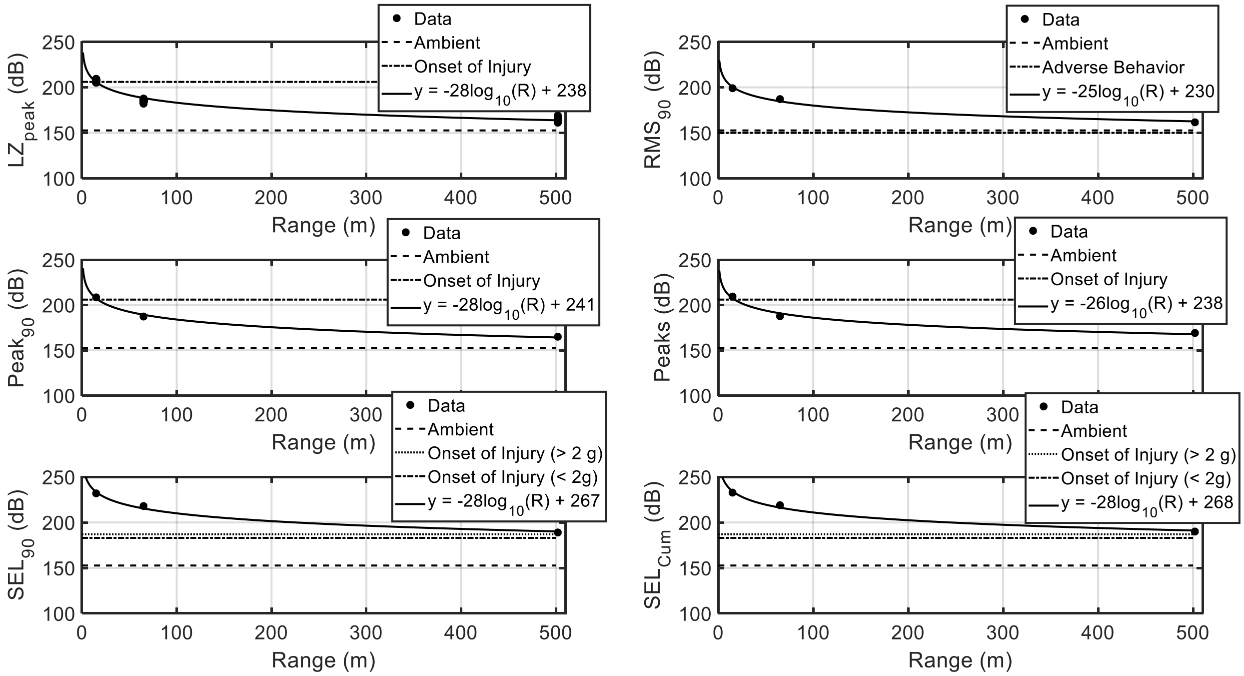


Figure 5-15. Best-fit regression curves from Suwannee River Bridge Pile 2 showing fit with all data (top-left); RMS$_{90}$ data (top-right); Peak$_{90}$ data (middle-left); Peak data (middle-right); SEL$_{90}$ data (bottom-left); and SEL$_{cum}$ data (bottom-right)

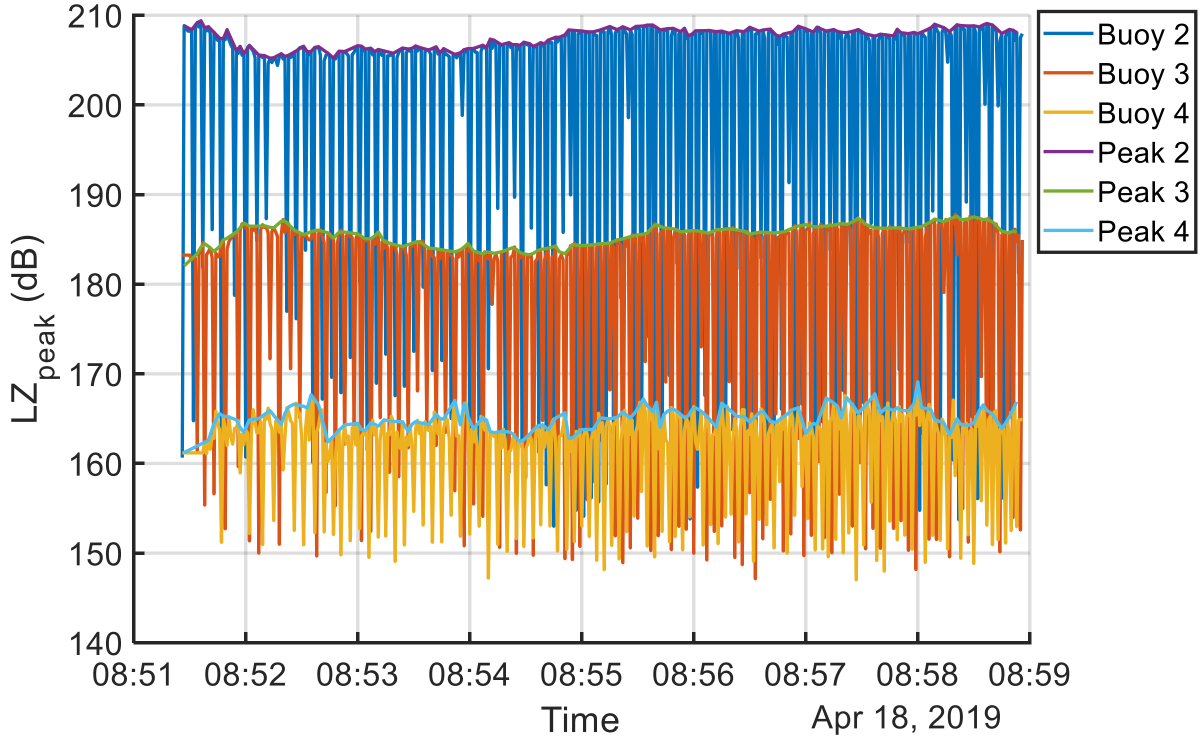


Figure 5-16. Isolated sound data from Suwannee River pile 2

Table 5-9. Numerical Data Summary for Suwannee River Bridge Pile 3

Buoy Name	**RMS_{90} (dB)**	**$Peak_{90}$ (dB)**	**SEL_{90} (dB)**	**Peak(dB)**	**SEL_{cum} (dB)**
Buoy 2	204.01	209.90	227.65	211.87	228.79
Buoy 3	188.75	160.36	212.01	187.92	213.02
Buoy 4	165.32	167.48	186.63	170.10	187.56
At Pile (from best-fit curve)	**234**	**228**	**260**	**241**	**261**
Transmission Loss Coefficient, *F* =					**26**

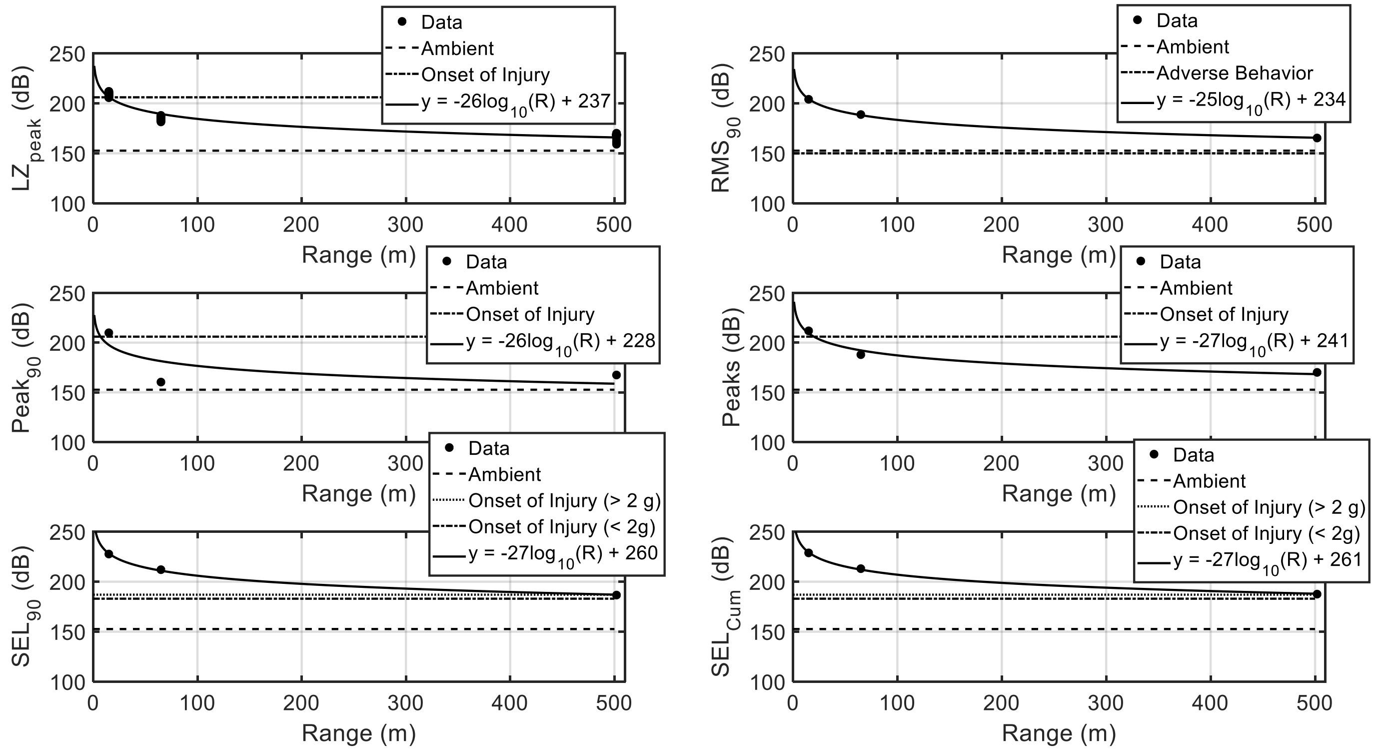


Figure 5-17. Best-fit regression curves from Suwannee River Bridge Pile 3 showing fit with all data (top-left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right)

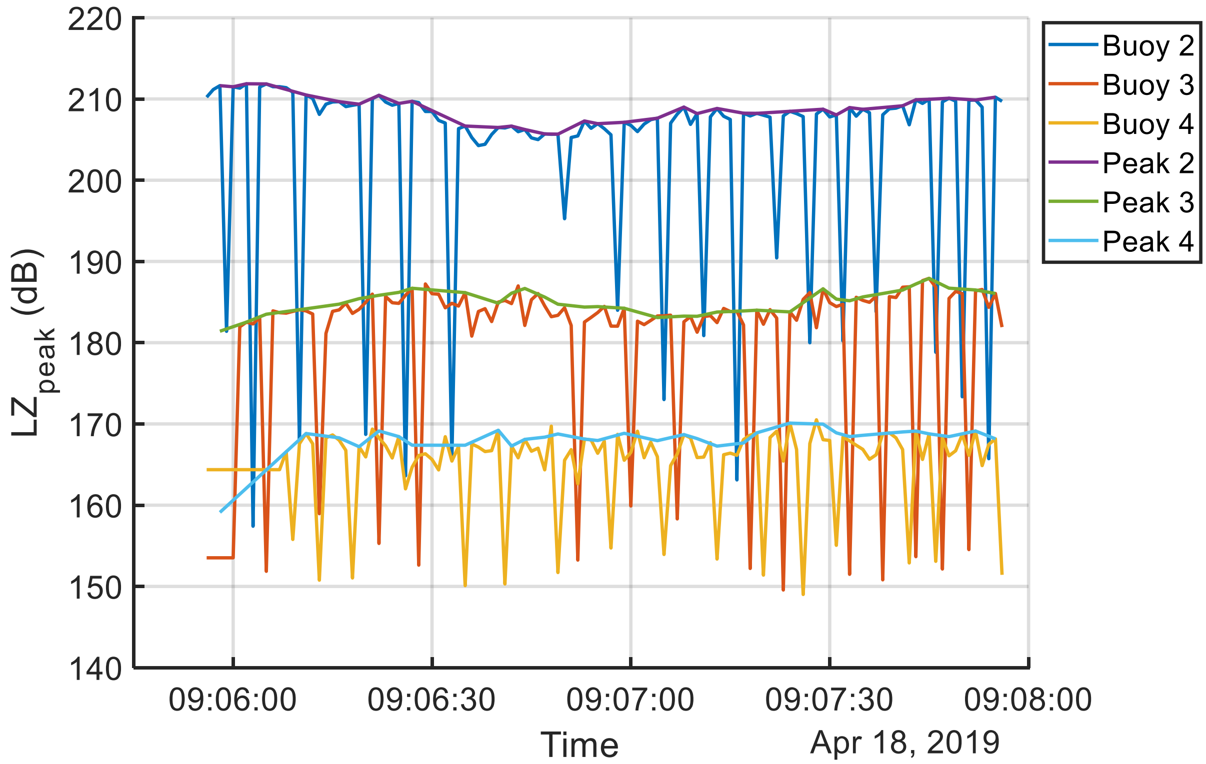


Figure 5-18. Isolated sound data from Suwannee River pile 3

As shown in these figures, data were very consistent through all three driven pile tests at this site. In all cases, the R-squared values were very high. Therefore, the *F-value* were also consistent and ranged between 25 and 28 with an average *F*-value of 26.3.

5.4 Bayway E Bridge

Tabular data from the Bayway E Bridge are presented below in Table 5-10 while best-fit regression curves are shown below in Figure 5-19 and signal data are presented in Figure 5-20:

Table 5-10. Numerical Data Summary for Bayway E Bridge

Buoy Name	RMS_{90} (dB)	$Peak_{90}$ (dB)	SEL_{90} (dB)	Peak(dB)	SEL_{cum} (dB)
Buoy 1	153.49	140.08	192.42	182.66	197.14
Buoy 2	136.98	133.09	174.70	170.52	178.86
Buoy 3	143.59	144.58	180.80	166.21	183.84
Buoy 4	146.33	140.62	183.84	164.32	187.68
At Pile (from best-fit curve)	**165**	**NA; Bad Fit**	**NA; Bad Fit**	**200**	**201**
				Transmission Loss Coefficient, *F* =	**8**

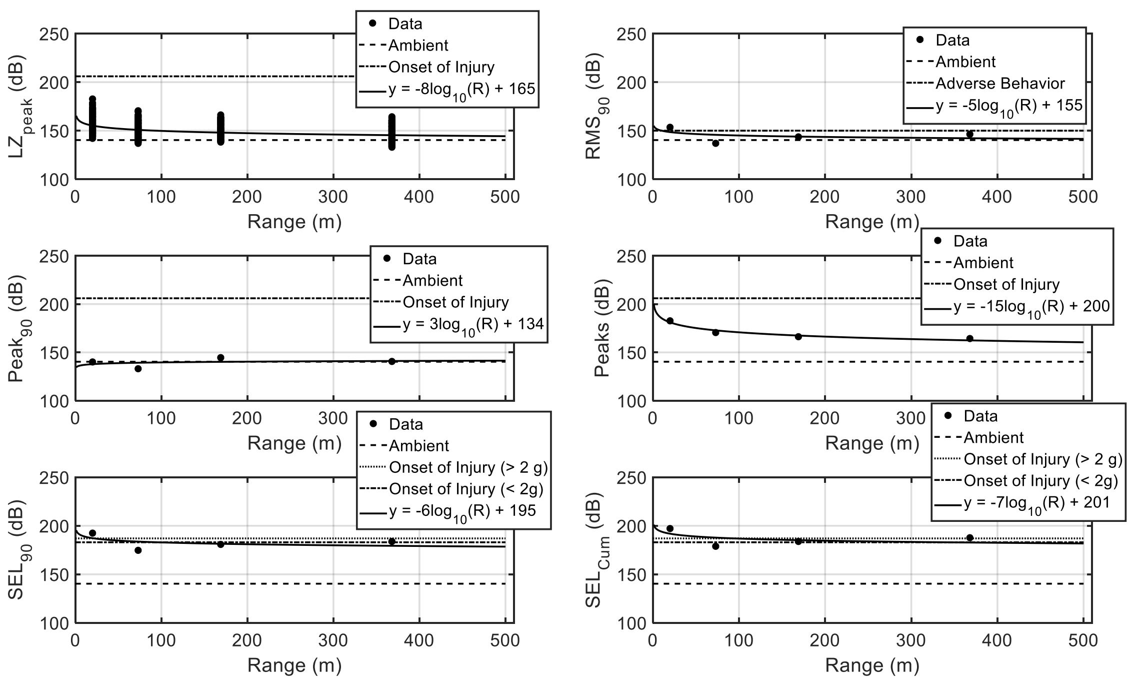


Figure 5-19. Best-fit regression curves from the Bayway E Bridge showing fit with all data (top-left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right)

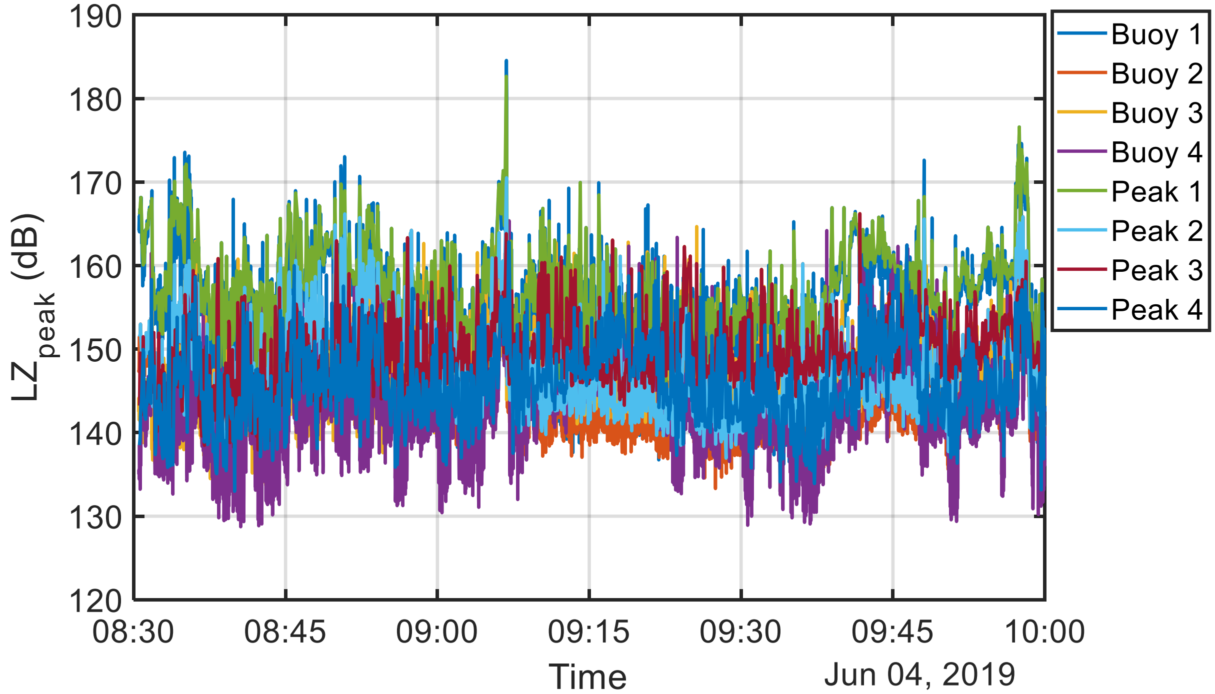


Figure 5-20. Isolated sound data from Bayway E Bridge

As shown, data fits were poor at this site. However, the measured LZ_{peak} data were very close to ambient noise data. As such, one may conclude that this pile vibrating did not produce much sound. Since little sound was produced, there was very little transmission loss that could be measured. The most meaningful conclusion from this site is that conditions at this site produced little noise when compared to the ambient noise already present in the water.

5.5 John Sims Parkway Bridge

Tabular data from the John Sims Parkway Bridge are presented below in Table 5-11 while best-fit regression curves are shown below in Figure 5-21 and signal data are presented in Figure 5-22:

Table 5-11. Numerical Data Summary for John Sims Parkway Bridge

Buoy Name	**RMS_{90} (dB)**	**$Peak_{90}$ (dB)**	**SEL_{90} (dB)**	**Peak(dB)**	**SEL_{cum} (dB)**
Buoy 1	180.12	188.81	213.47	191.14	214.71
Buoy 2	166.05	148.12	197.87	174.60	199.06
Buoy 3	155.70	156.62	186.11	162.69	187.20
Buoy 4	154.71	161.87	185.73	162.33	186.95
At Pile (from best-fit curve)	**218**	**206**	**255**	**234**	**256**
				Transmission Loss Coefficient, *F* =	**28**

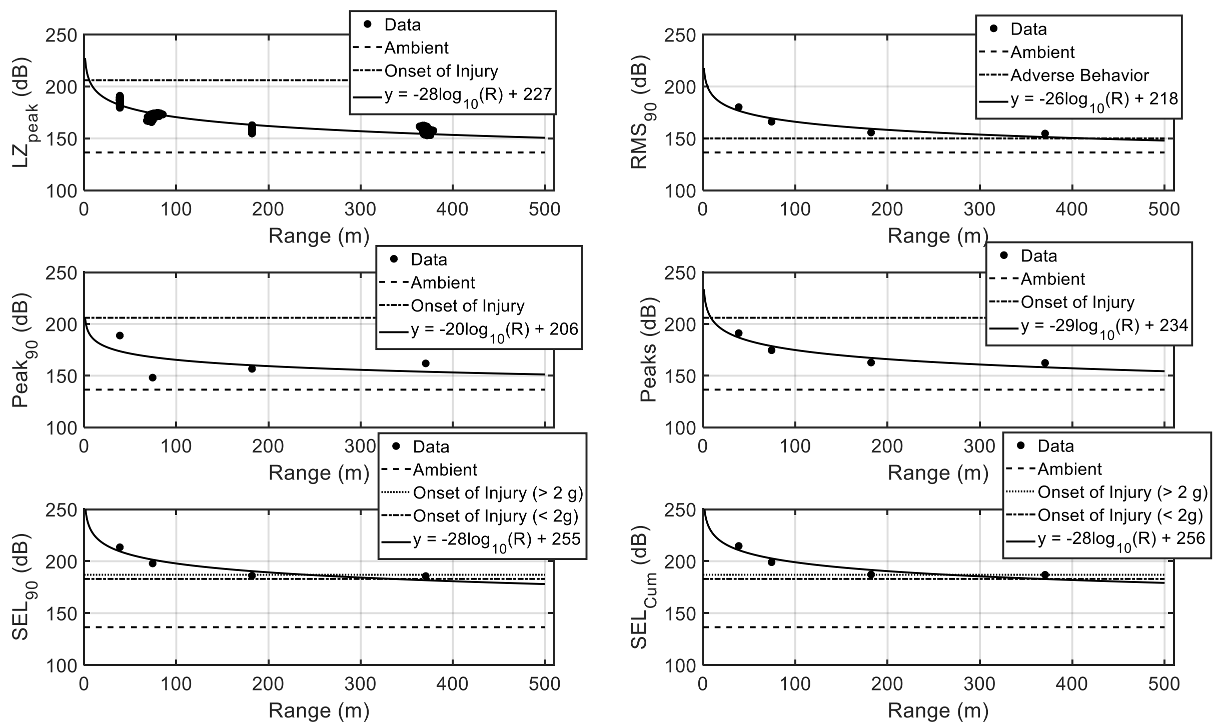


Figure 5-21. Best-fit regression curves from the John Sims Parkway Bridge showing fit with all data (top-left); RMS_{90} data (top-right); $Peak_{90}$ data (middle-left); Peak data (middle-right); SEL_{90} data (bottom-left); and SEL_{cum} data (bottom-right)

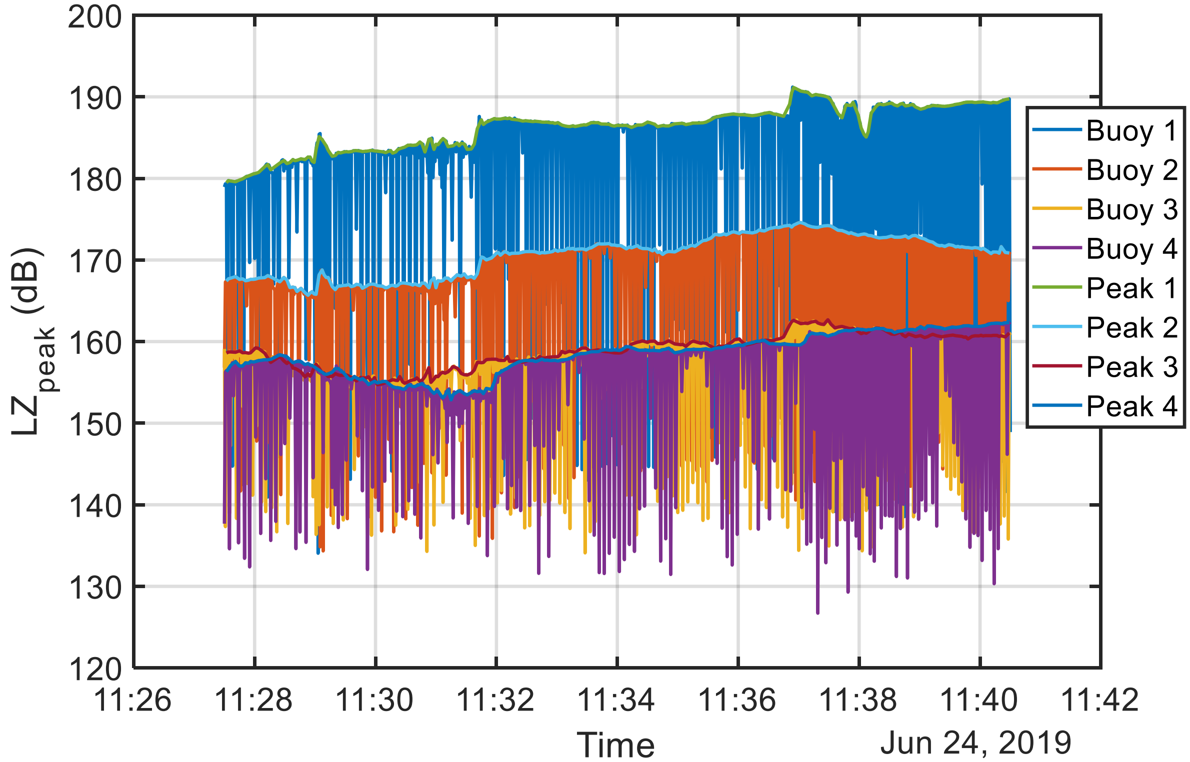


Figure 5-22. Isolated sound data from John Sims Parkway Bridge

As shown in the figures above, these data were very consistent and unlike Bayway E, represent an example of a very "clean" signal. Computed *F*-value for this site was 28.

5.6 Summary of *F* and *SEL*

Table 5-12 below presents a summary of *F* and worst-case *SEL* values for each of the sites visited over the past 6 months. The Bayway E site is marked with an asterisk because as stated above, very little noise was produced at this site and hence, there was not much transmission loss that could be measured.

Table 5-12. Summary table for all sites visited in the last six months

Site Name	Mean *F*-value	Mean Worst-Case SEL_{cum}
Dunn’s Creek	47	251
Ribault River Test Pile	48	272
Ribault River Production Piles	44	277
Suwannee River	26	268
Bayway E*	8*	201*
John Sims Parkway	28	256

As shown, except for the Bayway E site, which again, produced very little noise relative to ambient conditions, *F*-values were consistently above n *F-value* of 15 recommended by the current set of guidelines.

Chapter 6: Conclusions

As shown in the analysis section above, with the exception of the Bayway E site, which produced very little noise relative to ambient conditions, *F*-values were consistently above $F=15$ recommended by the current set of guidelines. Analysis also suggests that *SEL*-levels may be very high near the pile. The worst-case extrapolated SEL_{cum} was 277 dB relative to 1 μPa. For reference, this value is equivalent to 251 dB relative to 20 μPa (i.e., the threshold for human hearing). These values are comparable with values reported by Reinhall and Dahl (2011) and Dahl et al. (2015). However, these high *SEL*s are very localized. The higher *F*-values cause *SEL* to decrease quickly as one moves further away from the pile. In addition, as indicated, closer readings to the pile at future sites may show that these *SEL* values are overestimations.

The underestimation of the *F-value* using the practical spreading loss model can greatly modify the anticipated anthropogenic noise associated with pile driving. If the transmission losses are not accurately predicted there is an increase of uncertainty associated with underwater noise. This underestimation of the transmission loss may cause an undue amount of time and money spent on sound mitigation techniques and environmental permitting.

6.1 Recommendations for Improving System & Future Research

The obvious area for improvement during data analysis is associated with the GPS units. The John Sims Parkway Bridge dataset show what was envisioned when using GPS coordinates to track buoy location. Note in Figure 7-13, how buoy drift was clearly taken into account in the LZ_{peak} versus Range plot. While the rangefinder is capable of giving approximate data when the GPS units fail, the GPS data should produce more accurate regression curves. We believe switching to terrestrial-based GPS (as opposed to the currently-used satellite-based GPS) will help mitigate the GPS issue. Another area for improvement is with the reliability associated with the electronics on the hydrophone meters.

The third area for improvement is the position of the first buoy closest to the pile. Since *TL* obeys a base-10 logarithmic decay, it is important to capture readings close to the pile (as opposed to extrapolating these measurements). Often, due to construction barge placement, this is not possible. However, whenever possible in the future, attempts need to be made to get the first buoy as close to the pile as possible. This may result in lower extrapolated SEL values near the pile.

Underwater sound propagation and the associated transmission loss equations needs to be further investigated to find a model or set of models that can be used in practical applications such as environmental permitting and construction mitigation requirements. While studies are ongoing, the relevance and risk of pile driving noise is a relatively new development. Additional testing and data analysis needs to be completed to explore the extent to which piling driving variations and other geographical and environmental factors are involved in actual underwater sound transmission losses.

References

Buehler, D., Oestman, R., Reyff, J., Pommerenck, K., and Mitchell, B. (2015). "Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish." California Department of Transportation, Sacramento, CA.

Collins, M. D. (1993). "A Split-Step Pade Solution for the Parabolic Equation Method." *J. Acoust. Soc. Am.*, 93(1736-1742).

Dahl, P. E., Dall-Osto, D. R., and Farrell, D. M. (2015). "The Underwater Sound Field from Vibratory Pile Driving." *The Journal of the Acoustical Society of America*, 137, 3544-3554.

Etter, P. C. (2009) "Review of Ocean-Acoustic Models." *Proc., IEEE Oceans*.

Farcas, A., Thompson, P. M., and Merchant, N. D. (2015). "Underwater Noise Modelling for Environmental Impact Assessment." *Environmental Impact Assessment Review*, 57(2016), 114-122.

Jensen, F. B., Kuperman, W. A., Porter, M. B., and Schmidt, H. (2011). *Comptuational Ocean Acoustics*, Springer, London.

Porter, M. B. (1992). "The KRAKEN Normal Mode Program. Tech. Rep. NRL/MR/5120-92-6920." N. R. Laboratory, ed.Washington, DC.

Roberts, Clarke (2011). "What are A, C & Z Frequency Weightings?" NoiseNews, Cirrus Research PLC.

Reinhall, P. G., and Dahl, P. H. (2011). "An Investigation of Underwater Sound Propogation from Pile Driving." *WSDOT Research Report*, Washington State Department of Transportation, Office of Research and Library Services, Olympia, WA.

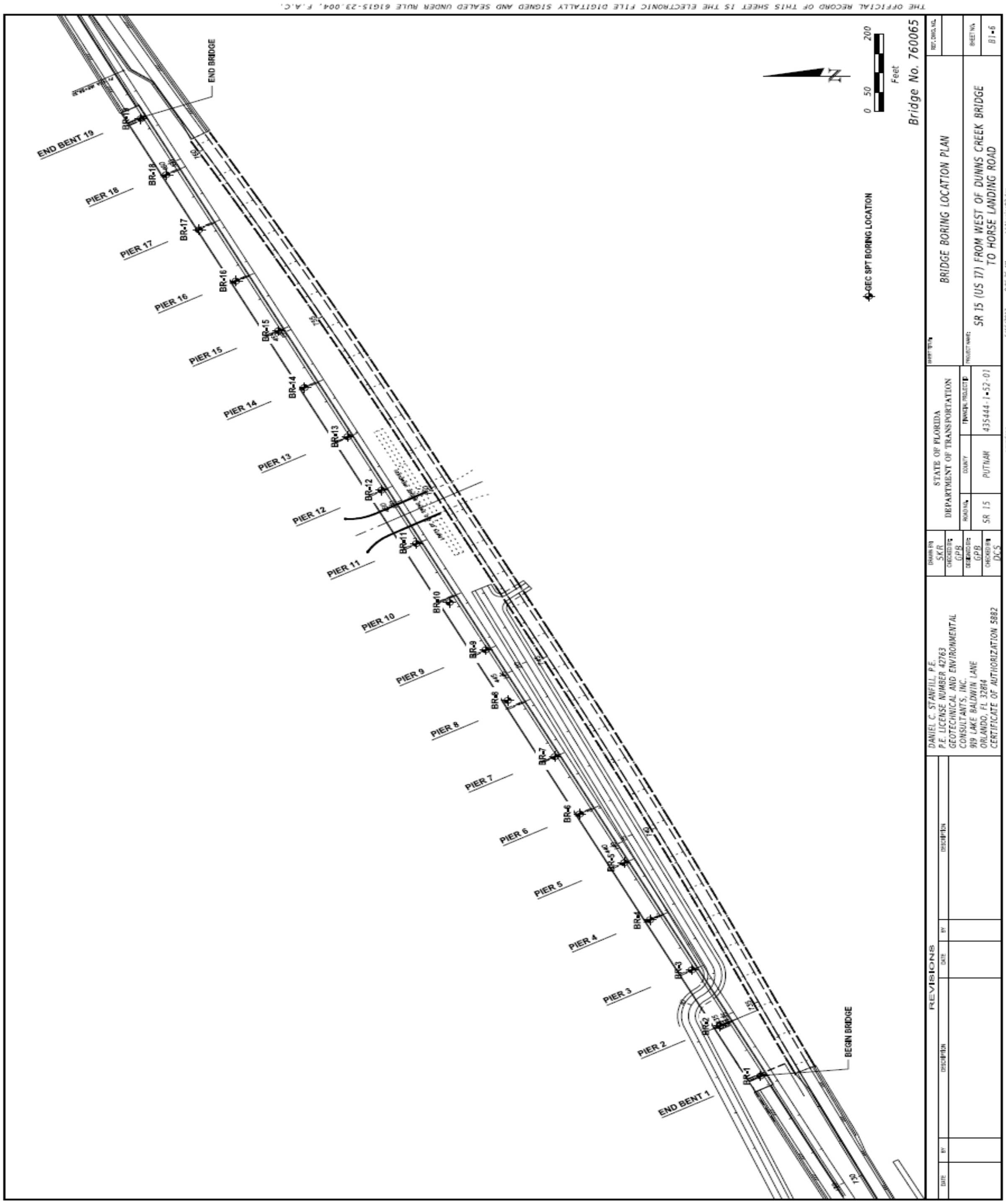
Reinhall, P. G., Dardis, T., and Dahl, P. H. (2015). "Underwater Noise Reduction of Marine Pile Driving using a Double Pile." Washington State Transportation Center, Seattle, WA.

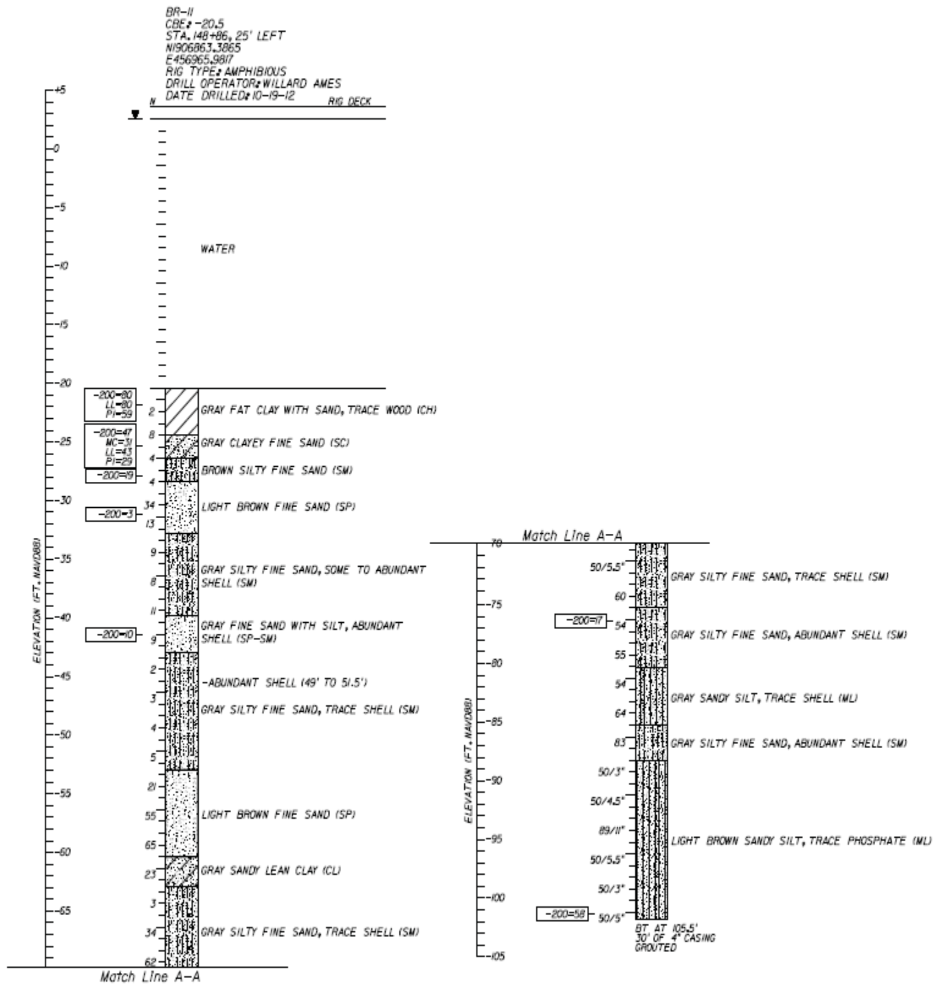
Tucholski, E. J. (2006). "Underwater acoustics and sonar sp411 handouts and notes fall 2006."US Naval Academy, Annapolis, MD.

Weston, D. E. (1971). "Intensity-Range Relations in Oceanographic Acoustics." *J. Sound Vib.*, 18, 271-287.

Appendix A: Dunn's Creek Geotechnical Information

A.1 Dunn's Creek Bridge Geotechnical Boring Logs





LEGEND

▼ ENCOUNTERED WATER LEVEL

CBE APPROXIMATE CREEK BOTTOM ELEVATION (FT. NAVD88)

N STANDARD PENETRATION RESISTANCE, BLOWS PER FOOT

50/3" NUMBER OF BLOWS FOR 3 INCHES OF PENETRATION

(SP) UNIFIED SOIL CLASSIFICATION SYMBOL

BT BORING TERMINATED AT SPECIFIED DEPTH (FEET) INDICATED

-200= PERCENT PASSING NO. 200 U.S. STANDARD SIEVE (FM 1-T 088)

MC= PERCENT NATURAL MOISTURE CONTENT (FM 1-T 265)

LL= LIQUID LIMIT (FM 1-T 089)

PI= PLASTICITY INDEX (FM 1-T 090)

SOILS LEGEND

SAND — SAND AND CLAY — SANDY SILT — SILTY SAND — CLAY

GENERAL NOTES

STANDARD PENETRATION TEST BORINGS WERE PERFORMED IN ACCORDANCE WITH ASTM D-1586. STANDARD PENETRATION RESISTANCES ARE SHOWN ON THE BORINGS AT THE TEST DEPTHS IN BLOWS PER FOOT UNLESS OTHERWISE NOTED.

SUBSURFACE CONDITIONS SHOWN ON THE BORINGS REPRESENT THE CONDITIONS ENCOUNTERED AT THE BORING LOCATIONS. ACTUAL CONDITIONS BETWEEN BORINGS MAY VARY FROM THOSE SHOWN. UNIFIED SOIL CLASSIFICATIONS SHOWN ON THE BORINGS ARE BASED ON VISUAL EXAMINATION AND THE LABORATORY TESTING SHOWN.

THE BORING LOCATIONS WERE ESTABLISHED USING A HAND HELD GPS UNIT AND ARE APPROXIMATE. THE APPROXIMATE BORING ELEVATIONS WERE PROVIDED BY CH2M HILL.

BASED ON REVIEW OF THE U.S. GEOLOGICAL SURVEY MAP ENTITLED "POTENTIOMETRIC SURFACE OF THE UPPER FLORIDAN AQUIFER IN ST. JOHNS RIVER WATER MANAGEMENT DISTRICT AND VICINITY, FLORIDA, MAY 2009" FOR THE PROJECT AREA. THE MAXIMUM ELEVATION OF THE ARTESIAN HEAD IS ESTIMATED TO RANGE FROM +20 TO +30 FT. NGVD. THE CONTRACTOR SHALL BE PREPARED TO HANDLE ARTESIAN HEAD LEVELS UP TO +30 FT. NGVD. ARTESIAN FLOW NOT OBSERVED WHILE DRILLING BR-11.

SPLIT SPOON SAMPLER:
INSIDE DIAMETER: 1.375 IN.
OUTSIDE DIAMETER: 2.0 IN.

AVERAGE HAMMER DROP: 30 IN.
HAMMER WEIGHT: 140 LBS.
HAMMER TYPE: SAFETY (MANUAL)

ENVIRONMENTAL CLASSIFICATION:
SUBSTRUCTURE:
STEEL: EXTREMELY AGGRESSIVE (SOIL MINIMUM RESISTIVITY=450 ohm-cm)
CONCRETE: EXTREMELY AGGRESSIVE (SOIL MINIMUM RESISTIVITY=450 ohm-cm)

CORRELATION OF STANDARD PENETRATION RESISTANCE WITH RELATIVE DENSITY AND CONSISTENCY OF SOIL

GRANULAR SOILS	N VALUE (blows per foot)	RELATIVE DENSITY
SANDS	0-4 4-10 10-30 30-50 OVER 50	VERY LOOSE LOOSE MEDIUM DENSE DENSE VERY DENSE
NON-GRANULAR SOILS	N VALUE (blows per foot)	CONSISTENCY
SILTS, CLAYS, MUCK, PEAT	0-2 2-4 4-8 8-15 15-30 OVER 30	VERY SOFT SOFT FIRM STIFF VERY STIFF HARD

Bridge No. 760065

REVISIONS					
DATE	BY	DESCRIPTION	DATE	BY	DESCRIPTION

DANIEL C. STANFILL, P.E.
P.E. LICENSE NUMBER 42763
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS, INC.
919 LAKE BALDWIN LANE
ORLANDO, FL 32814
CERTIFICATE OF AUTHORIZATION 5882

DRAWN BY: SKR
CHECKED BY: GPB
DESIGNED BY: GPB
CHECKED BY: DCS

STATE OF FLORIDA
DEPARTMENT OF TRANSPORTATION

ROAD NO.	COUNTY	FINANCIAL PROJECT ID
SR 15	PUTNAM	435444-1-52-01

SHEET TITLE: REPORT OF SPT BORINGS FOR BRIDGE

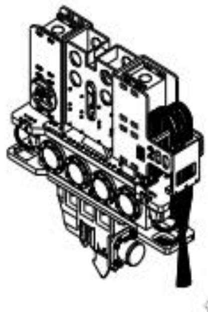
PROJECT NAME: SR 15 (US 17) FROM WEST OF DUNNS CREEK BRIDGE TO HORSE LANDING ROAD

REF. DWG. NO.

SHEET NO. B1-17

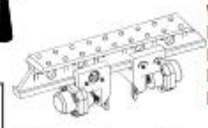
A.2 Dunn's Creek Bridge Vibratory Driver Specifications

APE Model 200 Vibratory Driver/Extractor with Model 700 Power Unit with 700 HP (522 kW)



Shows standard universal clamp attachment. See "optional attachments" literature for more information on other types of clamp attachments.

APE Wood Clamp

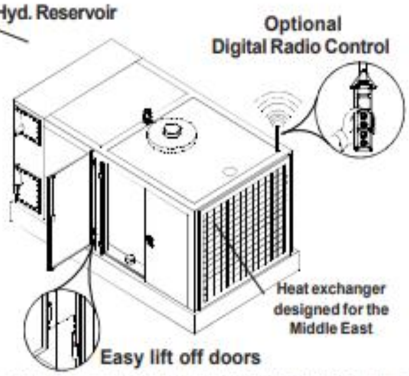


APE caisson clamps with beam for driving and extracting pipe piles

SPECIFICATIONS:	VIBRATOR Model 200
Eccentric moment	5,080 kg-cm (4400 in-lbs)
Frequency (variable)	0-1800 vpm
Driving force @ 1600 vpm	145 metric tons (160 US tons)
Driving force @ 1800 vpm	183 metric tons (202 US tons)
Amplitude	30 mm (1.17 in)
Maximum line pull	1,335 kN (150 US tons)
Suspended Weight (with universal clamp)	6,167 kg (13,600 lbs)
Length	256 cm (101 in)
Width throat	35 cm (14 in)
Width at widest point	43 cm (17 in)
Height (with 223 kN (30 ton) short suppressor & clamp	153 cm(60 in)
Height (with 1,335 kN/150 ton)(suppressor & 200 clamp)	238 cm (94 in)
Hydraulic hose length (standard)	46 meters (150 ft)
Hydraulic hose weight	680 kg (1,500 lbs)

Suspended weight drops when using smaller mini suppressor to 9,000 lbs. (4082 kg).
Suspended weight increases when using bias weights to 17,000 lbs. (7710 kg).

SPECIFICATIONS:	POWER UNIT Model 700
Engine CAT	C18 ACERT Tier III Certified
Power (Caterpillar)	522 kW (700 hp)
Operating speed (No Load)	800 to 2,100 rpm
Drive pressure (max)	344 bar (5,000 psi)
Drive flow (variable)	0-741 lpm (0-196 gpm)
Clamp pressure (max)	310 bar (5,000 psi*)
Clamp flow	41 lpm (10 gpm)
Weight	9,061 kg (19,975 lbs)
Length	401 cm (158 in)
Width	196 cm (77 in)
Height	259 cm (102 in)
Hydraulic reservior	2,498 liters (660 gal)
Fuel tank	662 liters (175 gal)



*All power unit components are designed to operate at 350 bar. The 200 has extremely large hydraulic motors for excellent performance at 282 bar. Engineers using the standard formula for horsepower requirements (psi x flow x .1714) should consult with APE engineers for a more complete understanding of how to properly calculate vibro performance. 200T also operates on APE Model 800 power unit with 801 horsepower (597 kW).

Advanced, profit generating features that are years ahead of the competition:

* *Patented multistage suppressor design reduces vibro weight and height while increasing line pull by 100%.*
* *Vibro will not shake the crane line or boom even during vibro "starting" and "stopping."*
* *Center safety pin shows pile crew and crane operator how much line pull is on pile and crane.*
* *Only vibro on market with detachable suppressor housings to fit any height and weight requirements.*
* *One piece helical gear/eccentric eliminates keyways, pins, splines, and bolts inside the gearbox.*
* *Heavy metal enhanced eccentric design reduces internal parts by up to 75% while increasing dynamic force.*
* *Giant spherical bearings allow for batter operations without damage and reduce heat for extremely long life.*
* *Computer designed gearbox is perfectly balanced with lowest center of gravity on the market.*
* *Rifle bored top plate eliminates all hoses on suppressor and to hydraulic motors. Mechanic's dream come true.*
* *Heavy duty clamp cylinder is machined from one piece of solid steel to eliminate o-rings and bolt-on guards.*
* *Power unit comes standard with spare hydraulic tank, tool kit, dual controls on pendant and control panel.*
* *Very simple open loop hydraulic system with highest quality valves with lighted indicators.*
* *Variable flow in both directions for use on drills, winches, hydraulic hammers, and other attachments.*
* *Oversized radiator and hydraulic oil cooler with proven performance in the heat of Saudi Arabia.*

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

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

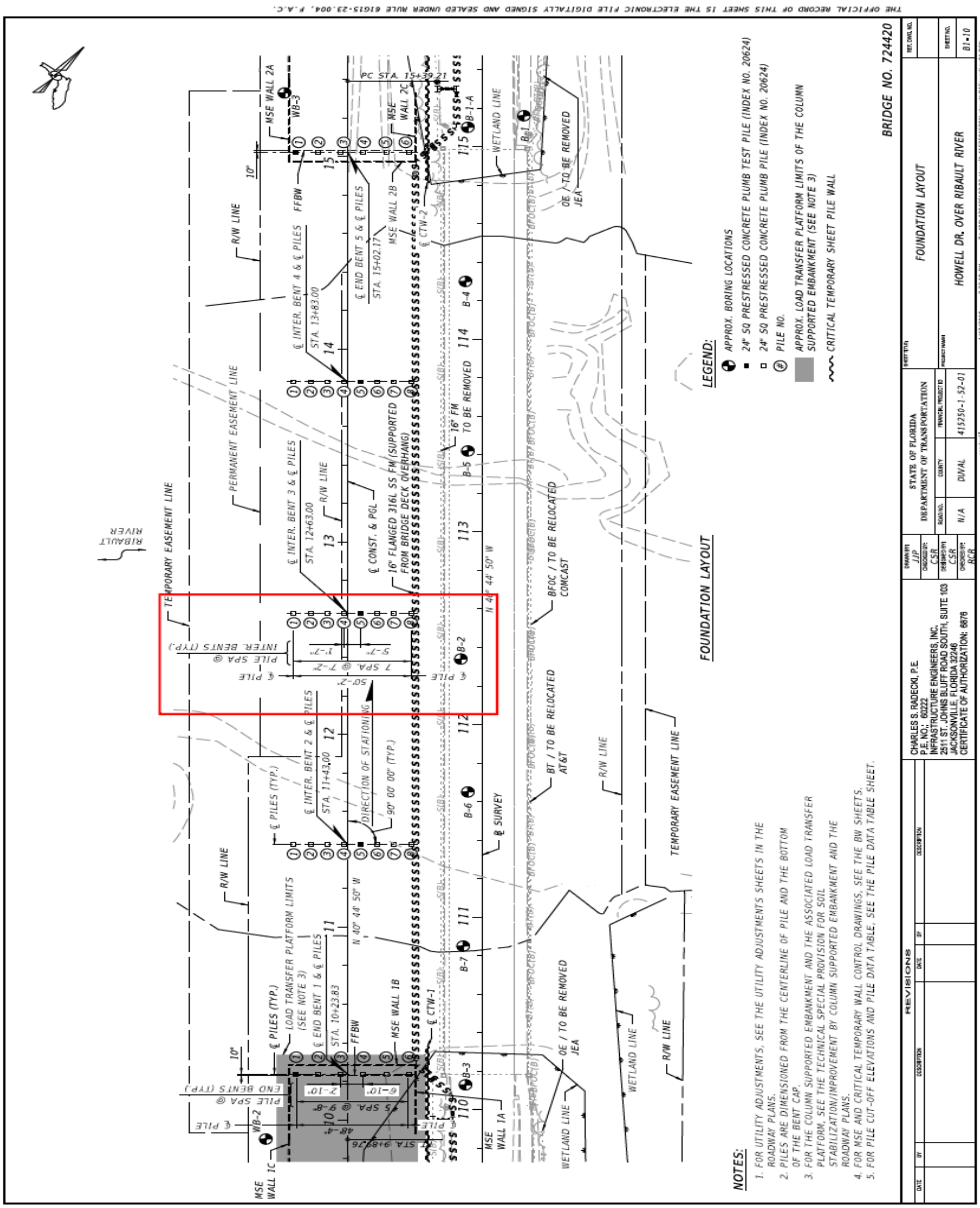
Due to constant improvements we must advise you to call APE for the latest available literature and specifications. 7/8/96

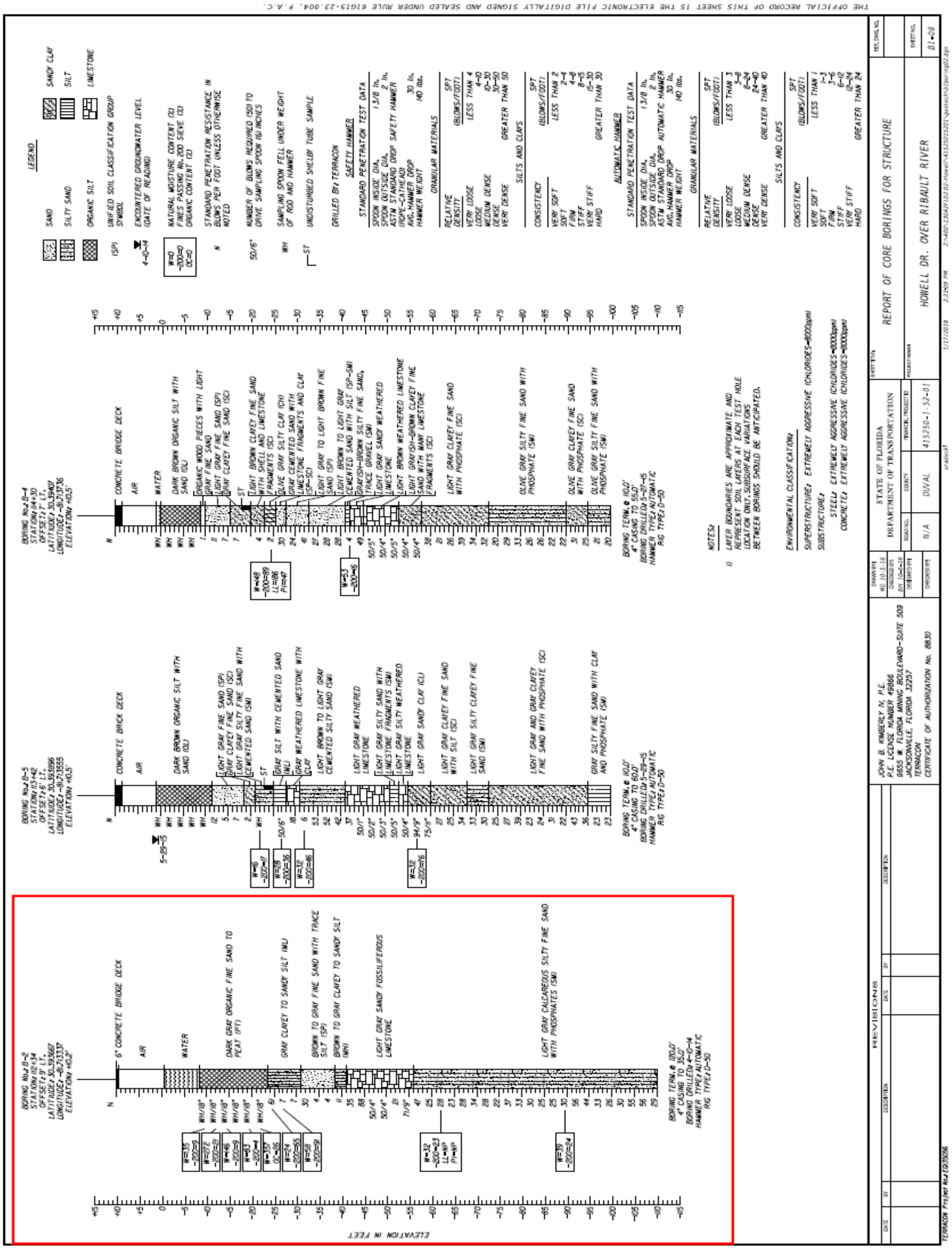
A.3 Dunn's Creek Pile Driving Logs

Since a construction trestle was monitored, pile driving logs were not recorded by the contractor.

Appendix B: Ribault River Geotechnical Information

B.1 Ribault River Bridge Geotechnical Boring Logs




REPORT OF CORE BORINGS FOR STRUCTURE
HOWELL DR. OVER RIBAULT RIVER
STATE OF FLORIDA
DEPARTMENT OF TRANSPORTATION
LEGEND

B.2 Ribault River Bridge Impact Driver Specifications

APE Model D50-52 Single Acting Diesel Impact Hammer

D50-52 in a stand-off.

Optional Variable Throttle Control

Drive Base Assembly

MODEL D50-52 (5.0 metric ton ram)

SPECIFICATIONS

Stroke at maximum rated energy	135 in (343 cm)
Maximum rated energy (Setting 4)	124,031 ft-lbs (167.44 kNm)
Seting 3	102,946 ft-lbs (138.98 kNm)
Seting 2	81,861 ft-lbs (110.51 kNm)
Minimum rated energy (Setting 1)	60,775 ft-lbs (82.05 kNm)
(Variable throttle allows for infinite fuel settings)	
Mximimum obtainable stroke	150 in (381 cm)
Maximum obtainable energy	144,243 ft-lbs (196 kNm)
Speed (blows per minute)	34-53

WEIGHTS (Approximate)

Piston	11,025 lbs (5,000 kg)
Anvil	2,255 lbs (1,023 kg)
Anvil cross sectional area	367.94 in² (2373.80 cm²)
Hammer weight (includes trip device)	25,882 lbs (11,737 kg)
Typical operating (weight with DB26 and H-beam insert)	31,184 lbs (14,142 kg)

CAPACITIES

Fuel tank (runs on diesel or bio-diesel)	23.1 gal (87.4 liters)
Oil tank	4.4 gal (16.65 liters)

CONSUMPTION

Diesel or Bio-diesel fuel	4.16 gal/hr (16 liters/hr)
Lubrication	0.39 gal/hr (1.47 liters/hr)
Grease	8 to 10 pumps every 20 minutes of operation time.

STRIKER PLATE

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

CUSHION MATERIAL

Type/Qty	Micarta / 2 each
Diameter	25 in (63.5 cm)
Thickness	1 in (25.4 mm)
Type/Qty	Aluminum / 3 each
Thickness	1/2 in (12.7 mm)
Diameter	25 in (63.5 cm)
Total Combined Thickness	3.5 in (8.89 cm) 491 in²
Area	(3167.74 cm²)
Elastic-modulus	285 ksi (1,965 mpa)
Coeff. of restitution	0.8

DRIVE CAP

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

INSERT WEIGHT

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

MINIMUM BOX LEAD SIZE/OPERATING LENGTH

Minimum box leader size	8 in x 32 in (20.32 cm x 81.28 cm)
Operating length as described above	354 in (900 cm)

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

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

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

B.3 Ribault River Bridge Test Pile Driving Logs

Excel 2016 (v 16.0)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

700-010-60
Construction
Nov-18

PILE DRIVING LOG

Structure No: 724420 Page No: 1 of 4

PROJECT No: 415250-1-52-01 Date: 5/7/19 Station No: 12 +63.00

PILE Size/Type: 24" SQ PCP Length (ft): 110.00 Bent/Pier No: 3 PILE No: 1

HAMMER Make/Model: APE D50 S/N: 201407705 Rated Energy (ft-lbs): 124 FT/LB Operating Rate (BPM): 34-53

REF Elev: +17.04 (REF 1) MIN TIP Elev: -45.00 PILE CUTOFF Elev: +8.40

DRIVING CRITERIA (DC): DC2 Elev:

Type: Test Pile DRIVING CRITERIA Inputs n/a for TP

DC Max Stk: Min Stk req'd for PR:

Notes: Full PDA by ECS

SC criteria (If applic): bpi @ ft Stk

DC1				DC2, input if applic.			
(1)	blows @		ft,	(6)	blows @		ft,
(2)	blows @		ft,	(7)	blows @		ft,
(3)	blows @		ft,	(8)	blows @		ft,
(4)	blows @		ft,	(9)	blows @		ft,
(5)	blows @		ft,	(10)	blows @		ft,

SCOUR Elev:

PILE CUSHION Thickness & Material: 24 in. x 24 in x 15 in. plywood

HAMMER CUSHION Thickness & Material: 2 x 1 in micarta + 3 x 0.5 in. aluminum

Pile Activity	Date	Start Time	Stop Time	Weather	Temp °F	Notes
Preforming	5/3/19	9:12AM	9:45AM	Cloudy	75	1, 2
Stand Pile	5/7/19	11:06AM	11:30 AM	Partly Cloudy	85	
DRIVE Pile	5/7/19	1:10PM	1:24PM	Partly Cloudy	85	

PILE DATA:

PAY ITEM No: 455-34-5 WORK ORDER No: N/A

MANUFACTURED By: CDS MFR's PILE No: HD-24-TP006 DATE CAST: 11/30/18

TBM/BM Elev: N/A TBM/BM Rod Read: N/A H.I. Elev: N/A

PRE-DRILLED Elev: N/A GROUND Rod Read: N/A GROUND Elev: -22.50

Manually input GROUND Elev (no sheet calc)

PREFORMED Elev: -45.00 Bottom of Excav Rod Read: N/A Bottom of Excav Elev: N/A

PILE HEAD Rod Read: N/A PILE HEAD Elev: +63.19 PILE TIP Elev: -46.81

PH Elev = REF - LP + PL = +63.19

Top of SOIL PLUG Elev (for Open Ended Pipe Piles & H-piles): Natural Ground Elev: N/A

Input 'Natural Ground EL' ONLY when natural ground surface is below embankment/fill material. Otherwise, leave this cell BLANK

SPLICE / EACH	PREFORMED HOLE	DYNAMIC LOAD TEST	PAY SET CHECK	NO PAY SET CHECK	REDRIVE	EXTRACTION	DRIVING OF SPLICE	PILE TYPE CODE	Plumb or Batter ? (click & select) ↓ PLUMB	PILE LENGTH (ft): ORIGINAL FURNISHED	PILE LENGTH (ft): TOTAL LENGTH WITH EXTENSION	Pile PENETRATION below GROUND (ft)	EXTENSION/BUILD UP: AUTHORIZED (ft)	EXTENSION/BUILD UP: ACTUAL (ft)
0	1	1	0	0	0	0	0	1		110.00	110.00	24.31	N/A	N/A

Pile PENETRATION (ft), below: GROUND: 24.31 ft

CTQP Trainee (supervised by the Qualified Inspector) experiencing the full pile installation & log inspection: Name: TIN:

Qualified Inspector - I certify the Pile Driving Log content, and as applicable, the above CTQP Trainee's participation during this pile installation: Name & TIN: Sean Johnson J52578470 Signature:

DC:

STATE OF FLORIDA DOT

Min Tip | 1 ft to c/o | c/o

700-010-60
Construction
Nov-18

PILE DRIVING LOG

Structure No.: 724420 Depth Table Extended (ft): Bent/Pier No.: 3 Pile No.: 1

Depth (Input Start LP↓)	REF		Blows	Stroke	Notes	Depth	REF		Blows	Stroke	Notes	Depth	REF		Blows	Stroke	Notes
0.00	1	1.00				33.00	-	34.00				**63.85**	-	64.00			
1.00	-	2.00				34.00	-	35.00				64.00	-	65.00			
2.00	-	3.00				35.00	-	36.00				**65.00**	-	69.00			
3.00	-	4.00				36.00	-	37.00				69.00	-	70.00			
4.00	-	5.00				37.00	-	38.00				70.00	-	71.00			
5.00	-	6.00				38.00	-	39.00				71.00	-	72.00			
6.00	-	7.00				39.00	-	40.00				72.00	-	73.00			
7.00	-	8.00				40.00	-	41.00				73.00	-	74.00			
8.00	-	9.00				41.00	-	42.00				74.00	-	75.00			
9.00	-	10.00				42.00	-	43.00				75.00	-	76.00			
10.00	-	11.00				43.00	-	44.00				76.00	-	77.00			
11.00	-	12.00				44.00	-	45.00				77.00	-	78.00			
12.00	-	13.00				45.00	-	46.00				78.00	-	79.00			
13.00	-	14.00				46.00	-	47.00				79.00	-	80.00			
14.00	-	15.00				47.00	-	48.00				80.00	-	81.00			
15.00	-	16.00				48.00	-	49.00				81.00	-	82.00			
16.00	-	17.00				49.00	-	50.00				82.00	-	83.00			
17.00	-	18.00				50.00	-	51.00				83.00	-	84.00			
18.00	-	19.00				51.00	-	52.00				84.00	-	85.00			
19.00	-	20.00				52.00	-	53.00				85.00	-	86.00			
20.00	-	21.00				53.00	-	54.00				86.00	-	87.00			
21.00	-	22.00				54.00	-	55.00				87.00	-	88.00			
22.00	-	23.00				55.00	-	56.00				88.00	-	89.00			
23.00	-	24.00				56.00	-	57.00				89.00	-	90.00			
24.00	-	25.00				57.00	-	58.00	6	6	F1, 3	90.00	-	91.00			
25.00	-	26.00				58.00	-	59.00	13	6.3		91.00	-	92.00			
26.00	-	27.00				59.00	-	60.00	11	6.7		92.00	-	93.00			
27.00	-	28.00				60.00	-	61.00	13	6.4		93.00	-	94.00			
28.00	-	29.00				61.00	-	62.00	15	6.6		94.00	-	95.00			
29.00	-	30.00				62.00	-	63.00	17	6.6		95.00	-	96.00			
30.00	-	31.00				**63.00**	-	63.67	64	7	F4, 4	96.00	-	97.00			
31.00	-	32.00				**63.67**	-	63.77	20	7.5	F2, 5	97.00	-	98.00			
32.00	-	33.00				**63.77**	-	63.85	20	7.5	F1, 6, 7	98.00	-	99.00			

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

700-010-60
Construction
Nov-18

PILE DRIVING LOG

Structure No: 724420

Page No: 3 of 4

REF inputs & Notes

PROJECT No: 415250-1-52-01

Bent/Pier No: 3

PILE No.: 1

REF No.	Input REF EL ↓	*Calculated LP values for each REF used			Input REF description (template, stringline, etc.) for each REF used: ↓
		LP min tip	LP c/o-1	LP c/o	
1	+17.04	62.04	117.64	118.64	Top of pocket.
2					
3					
4					
5					

Standard Notes & Note No.'s 1-28

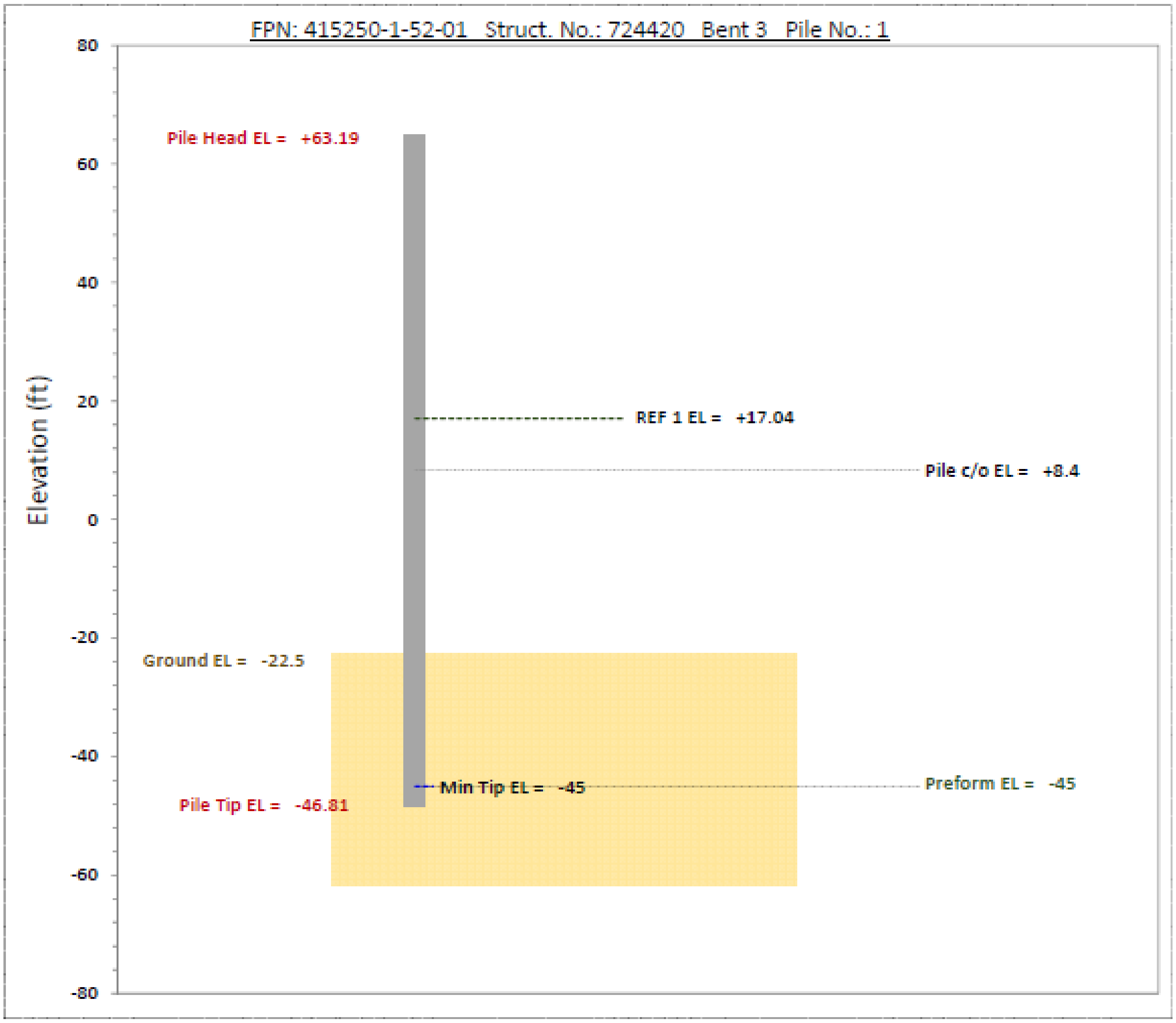
Std. Notes:	↓ = Pile Ran, F1, F2, F3, F4 = (Fuel Settings 1-4), ST = stop, CC = cushion change, HR = high rebound, TP = Test Pile, DC = Driving Criteria, PR = Practical Refusal, SC = set check, DLT = Dyn. Load Test
Note 1:	The contractor uses a 60 ft. sheet pile and vibratory hammer to break up the hard layer. The sheet pile is marked to
Note 2:	insure that it is not vibrated past minimum tip. They complete drilling to a preformed depth of -45.0 ft.
Note 3:	Contractor dry fires hammer from 57.0 ft. to 57.5 ft. in order to safely seat pile in firm material.
Note 4:	ECS changes to fuel setting 4, to observe stresses on pile, and immediately stops drive at 1317 to mark pile for inches.
Note 5:	Resumed drive at 1319 and drove pile for 20 blows on fuel setting 2. Pile moved 1.25 inches.
Note 6:	Stopped drive at 1320, changed fuel setting to 1, and resumed drive at 1323.
Note 7:	Practical refusal was reached with 20 blows for 1.0 inch, and a 7.5 ft stroke.
Note 8:	
Note 9:	
Note 10:	
Note 11:	
Note 12:	
Note 13:	
Note 14:	
Note 15:	
Note 16:	
Note 17:	
Note 18:	
Note 19:	
Note 20:	
Note 21:	
Note 22:	
Note 23:	
Note 24:	
Note 25:	
Note 26:	
Note 27:	
Note 28:	

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

700-010-60
Construction
Nov-18

PILE DRIVING LOG

	Structure No: 724420	Page No: 4 of 4	
		Sketch	
PROJECT No: 415250-1-52-01	Bent/Pier No: 3	PILE No.: 1	



PLUMB pile, as depicted in this Pile Sketch

Pile Bearing: (click on yellow shaded cell below, and select basis for Pile Bearing acceptance that applies)

Click here to select applicable bearing capacity related input: If none of the conditions below applies, type condition under which the pile was accepted.

Pile Penetration:

Pile Tip EL ≤ bottom EL of Preformed or Predrilled pile hole, meets 455-5 Penetration Requirements.

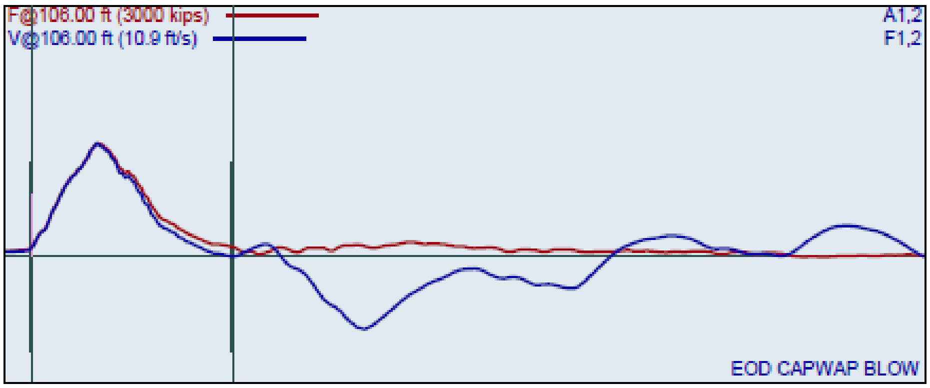
Current Pile Tip EL ≤ Min Tip EL in plans, meets 455-5 Penetration Requirements.

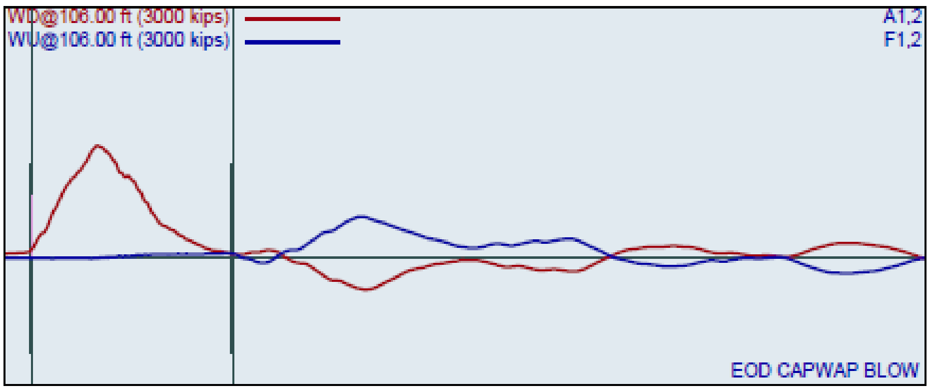
Min Tip EL is input on the log. Therefore, the 10-20 ft of penetration into firm/soft material, in accordance with 455-5 Penetration Requirements, does not apply.

B.4 Ribault River Bridge Test Pile PDA (Pile Driving Analyzer) Results

ECS Florida LLC
Pile Driving Analyzer ® (PDA)

HOWELL AT RIBAULT IB3, PILE 1 ID





Project Information
PROJECT: HOWELL AT RIBAULT
PILE NAME: IB3, PILE 1 ID
DESC: INITIAL DRIVE
PDA OWNER: ECS Florida LLC
SERIAL NUMBER: 3942L
OPERATOR: ECS-AT
FILE: IB3, PILE 5 ID.pda
07May2019 01:16:14 PM
Blow number 90

Pile Properties

LE	106.00 ft
AR	576.00 in^2
EM	6996 ksi
SP	0.150 k/ft3
WS	14700.0 ft/s
WC	14671.3 ft/s
EA/C	274.1 ksec/ft
2L/C	14.45 ms
JC	0.40
LP	63.16 ft

Quantity Results

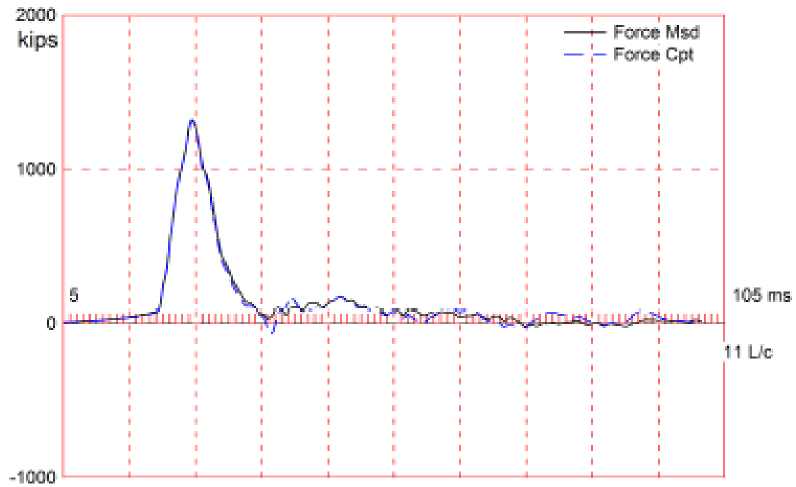
CSI	2.51 ksi
CSX	2.33 ksi
CSB	2.41 ksi
TSX	0.44 ksi
EMX	28.8 k-ft
ETR	23.2 %
STK	7.21 ft
RX4	1040 kips
RMX	1040 kips
RX9	980 kips
BTA	100.0 %
FVP	0.99

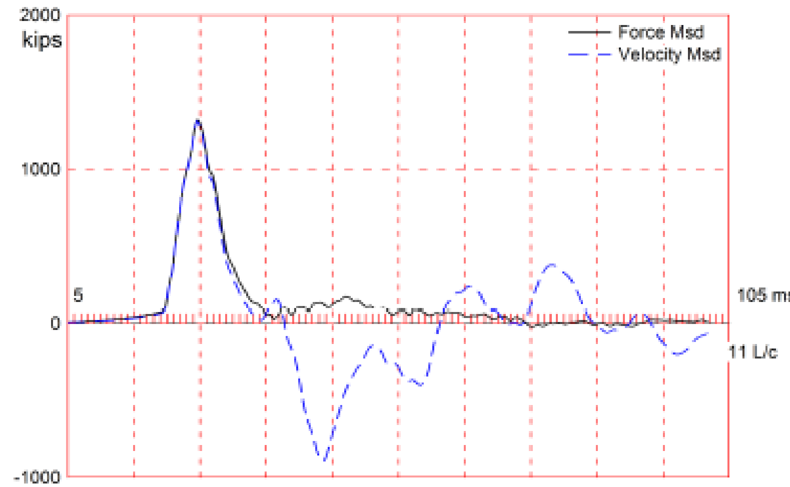
Sensors
A1 (PR): [K2626] 342 mv/6.4v/5000g (0.98) VF6
A2 (PR): [K6138] 352 mv/6.4v/5000g (0.98) VF6
F1 : [M753] 144.2 PDICAL (1.02) FF6
F2 : [G093] 101.2 PDICAL (1.02) FF6
CLIP: OK

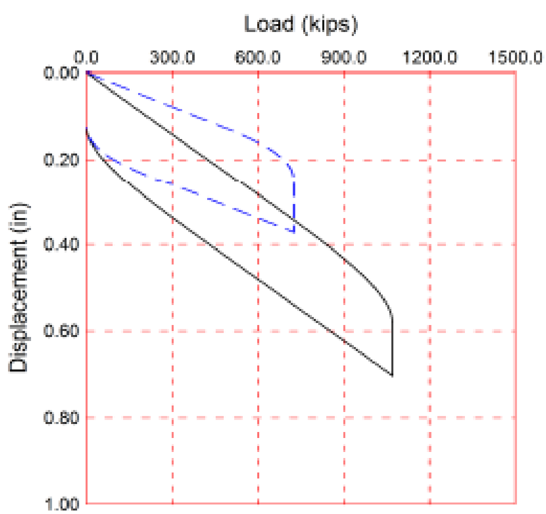
Version 2018.30

HOWELL AT RIBAULT; Pile: IB3, PILE 1 ID; INITIAL DRIVE; Blow: 91 (Test: 07-May-2019 13:16:)
ECS Florida LLC

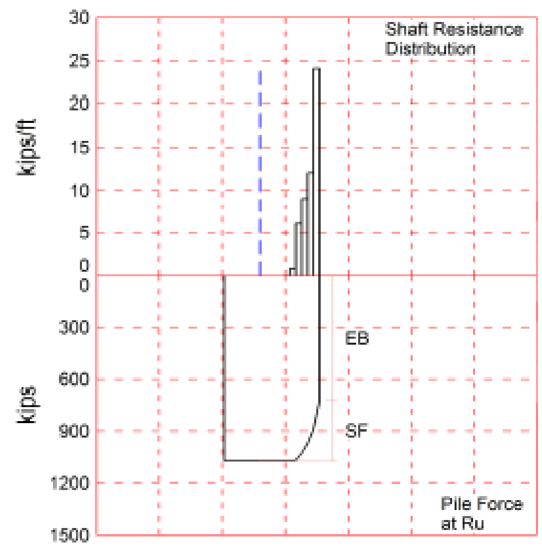
07-May-2019
CAPWAP(R) 2014-3







RU = 1071.0 kips
SF = 345.0 kips
EB = 726.0 kips
Dy = 0.58 in
Dx = 0.70 in
SET/BI = 0.13 in



Length b. Sensors	106.0 ft
Embedment	63.2 ft
Top Area	576.0 in²
End Bearing Area	576.0 in²
Top Perimeter	8.00 ft
Top E-Modulus	6996 ksi
Top Spec. Weight	150.0 lb/ft³
Top Wave Spd.	14700 ft/s
Overall W.S.	14700 ft/s
Match Quality	4.19
Top Compr. Stress	2.3 ksi
Max Compr. Stress	2.3 ksi
Max Tension Stress	-0.48 ksi
Avg. Shaft Quake	0.17 in
Toe Quake	0.19 in
Avg. Shaft Smith Dpg.	0.32 s/ft
Toe Smith Damping	0.07 s/ft

B.5 Ribault River Bridge Production Pile Driving Logs

Excel 2016 (v 16.0) — STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION — 700-010-60 Construction Nov-18

PILE DRIVING LOG

Structure No: 724420 — Page No: 1 of 4

PROJECT No: 415250-1-52-01 — Date: 6/10/19 — Station No: 12 + 63.00

PILE Size/Type: 24" SQ PCP — Length (ft): 60.00 — Bent/Pier No: 3 — PILE No: 2

HAMMER Make/Model: APE D50 — S/N: 201407705 — Rated Energy (ft-lbs): 124 FT/LB — Operating Rate (BPM): 34-53

REF Elev: +4.50 (REF 1) — MIN TIP Elev: -45.00 — PILE CUTOFF Elev: +8.40

DRIVING CRITERIA (DC): — DC2 Elev:

Type: Prod - DC

DC Max Stk: 8.5 FT. — Min Stk req'd for PR: 7.0 FT

Notes:

SC criteria (if applic): bpi @ ft Stk

	DC1			DC2, input if applic.	
(1)	72 blows @ 7.00 ft,		(6)	blows @	ft,
(2)	66 blows @ 7.50 ft,		(7)	blows @	ft,
(3)	60 blows @ 8.00 ft,		(8)	blows @	ft,
(4)	blows @ ft,		(9)	blows @	ft,
(5)	blows @ ft,		(10)	blows @	ft,

SCOUR Elev:

PILE CUSHION Thickness & Material: 24 in. x 24 in x 15 in. plywood

HAMMER CUSHION Thickness & Material: 2 x 1 in micarta + 3 x 0.5 in. aluminum

Pile Activity	Date	Start Time	Stop Time	Weather	Temp °F	Notes
Preforming	6/7/19	11:10am	11:26am	Partly Cloudy	85	1, 2
Preforming	6/7/19	3:00pm	3:25pm	Partly Cloudy	90	3
Stand Pile	6/10/19	10:06am	10:15am	Sunny	82	
DRIVE Pile	6/10/19	12:40pm	12:51pm	Sunny	85	

PILE DATA:

PAY ITEM No: 455-34-5 — WORK ORDER No: N/A

MANUFACTURED By: CDS — MFR's PILE No: HD-24-035 — DATE CAST: 5/29/19

TBM/BM Elev: N/A — TBM/BM Rod Read: N/A — H.I. Elev: N/A

PRE-DRILLED Elev: N/A — GROUND Rod Read: N/A — GROUND Elev: -22.50

Manually input GROUND Elev (no sheet calc)

PREFORMED Elev: -45.00 — Bottom of Excav Rod Read: N/A — Bottom of Excav Elev: N/A

PILE HEAD Rod Read: N/A — PILE HEAD Elev: +14.58 — PILE TIP Elev: -45.42

PH Elev = REF - LP + PL = +14.58

Top of SOIL PLUG Elev (for Open Ended Pipe Piles & H-piles): — Natural Ground Elev: N/A

Input 'Natural Ground EL' ONLY when natural ground surface is below embankment/fill material. Otherwise, leave this cell BLANK

SPLICE / EACH	PREFORMED HOLE	DYNAMIC LOAD TEST	PAY SET CHECK	NO PAY SET CHECK	REDRIVE	EXTRACTION	DRIVING OF SPLICE	PILE TYPE CODE	Plumb or Batter ? (click & select) ↓	PILE LENGTH (ft) ORIGINAL FURNISHED	PILE LENGTH (ft) TOTAL LENGTH WITH EXTENSION	Pile PENETRATION below GROUND (ft)	EXTENSION/BUILD UP AUTHORIZED (ft)	EXTENSION/BUILD UP ACTUAL (ft)
									PLUMB					
0	1	0	0	0	0	0	0	1		60.00	60.00	22.92	N/A	N/A

Pile PENETRATION (ft), below: GROUND: 22.92 ft

CTQP Trainee (supervised by the Qualified Inspector) experiencing the full pile installation & log inspection: — Name: William S. Middleton — TIN: M34393771

Qualified Inspector - I certify the Pile Driving Log content, and as applicable, the above CTQP Trainee's participation during this pile installation: — Name & TIN: Sean Johnson J52578470 — Signature: Sean D. Johnson

DC: DC1: 72 blows @ 7 ft stk, 66 @ 7.5, 60 @ 8,

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Min Tip | 1 ft to c/o | c/o

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PILE DRIVING LOG

Structure No.: 724420 Depth Table Extended (ft): Bent/Pier No.: 3 Pile No.: 2

Depth Input Start LP↓	REF		Blows	Stroke	Notes	Depth	REF		Blows	Stroke	Notes	Depth	REF		Blows	Stroke	Notes
0.00	1	1.00				33.00	-	34.00					-				
1.00	-	2.00				34.00	-	35.00					-				
2.00	-	3.00				35.00	-	36.00					-				
3.00	-	4.00				36.00	-	37.00	2		4		-				
4.00	-	5.00				37.00	-	38.00	3				-				
5.00	-	6.00				38.00	-	39.00	2		F1		-				
6.00	-	7.00				39.00	-	40.00			!		-				
7.00	-	8.00				40.00	-	41.00			!		-				
8.00	-	9.00				41.00	-	42.00			!		-				
9.00	-	10.00				42.00	-	43.00			!		-				
10.00	-	11.00				43.00	-	44.00			!		-				
11.00	-	12.00				44.00	-	45.00	11	5.5			-				
12.00	-	13.00				45.00	-	46.00	16	5.6			-				
13.00	-	14.00				46.00	-	47.00	16	5.6			-				
14.00	-	15.00				47.00	-	48.00	37	6.4			-				
15.00	-	16.00				48.00	-	49.00	31	7			-				
16.00	-	17.00				**49.00**	-	49.83	70	7.7			-				
17.00	-	18.00				**49.83**	-	49.92	20	7.7	5, 6		-				
18.00	-	19.00				**49.92**	-	50.00					-				
19.00	-	20.00				50.00	-	51.00					-				
20.00	-	21.00				**51.00**	-	54.00					-				
21.00	-	22.00				54.00	-	55.00					-				
22.00	-	23.00				55.00	-	56.00					-				
23.00	-	24.00				56.00	-	57.00					-				
24.00	-	25.00					-						-				
25.00	-	26.00					-						-				
26.00	-	27.00					-						-				
27.00	-	28.00					-						-				
28.00	-	29.00					-						-				
29.00	-	30.00					-						-				
30.00	-	31.00					-						-				
31.00	-	32.00					-						-				
32.00	-	33.00					-						-				

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PILE DRIVING LOG

Structure No: 724420

Page No: 3 of 4
REF inputs & Notes

PROJECT No: 415250-1-52-01

Bent/Pier No: 3

PILE No.: 2

REF No.	Input REF EL ↓	LP min tip	LP c/o-1	LP c/o	Input REF description (template, stringline, etc.) for each REF used: ↓
		*Calculated LP values for each REF used			
1	+4.50	49.50	55.10	56.10	Top of pocket.
2					
3					
4					
5					

Standard Notes & Note No.'s 1-28

Std. Notes:	↓ = Pile Ran, F1, F2, F3, F4 = (Fuel Settings 1-4), ST = stop, CC = cushion change, HR = high rebound,
	TP = Test Pile, DC = Driving Criteria, PR = Practical Refusal, SC = set check, DLT = Dyn. Load Test
Note 1:	The contractor intially drills to -40.0. The contractor uses a 60 ft. sheet pile and vibratory hammer to break up the
Note 2:	hard layer. The sheet pile is marked to insure that it is not vibrated past minimum tip. They complete drilling to a
Note 3:	formed depth of -45.0 ft.
Note 4:	Contractor dry fires hammer from 36.0 ft. to 38.0 ft. in order to safely seat pile in firm material.
Note 5:	Practical refusal was reached with 20 blows for 1.0 inch, and a 7.7 ft stroke. Cushions have 208 blows. They will be
Note 6:	used, per driving criteria, to start the drive on pile 3.
Note 7:	
Note 8:	
Note 9:	
Note 10:	
Note 11:	
Note 12:	
Note 13:	
Note 14:	
Note 15:	
Note 16:	
Note 17:	
Note 18:	
Note 19:	
Note 20:	
Note 21:	
Note 22:	
Note 23:	
Note 24:	
Note 25:	
Note 26:	
Note 27:	
Note 28:	

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

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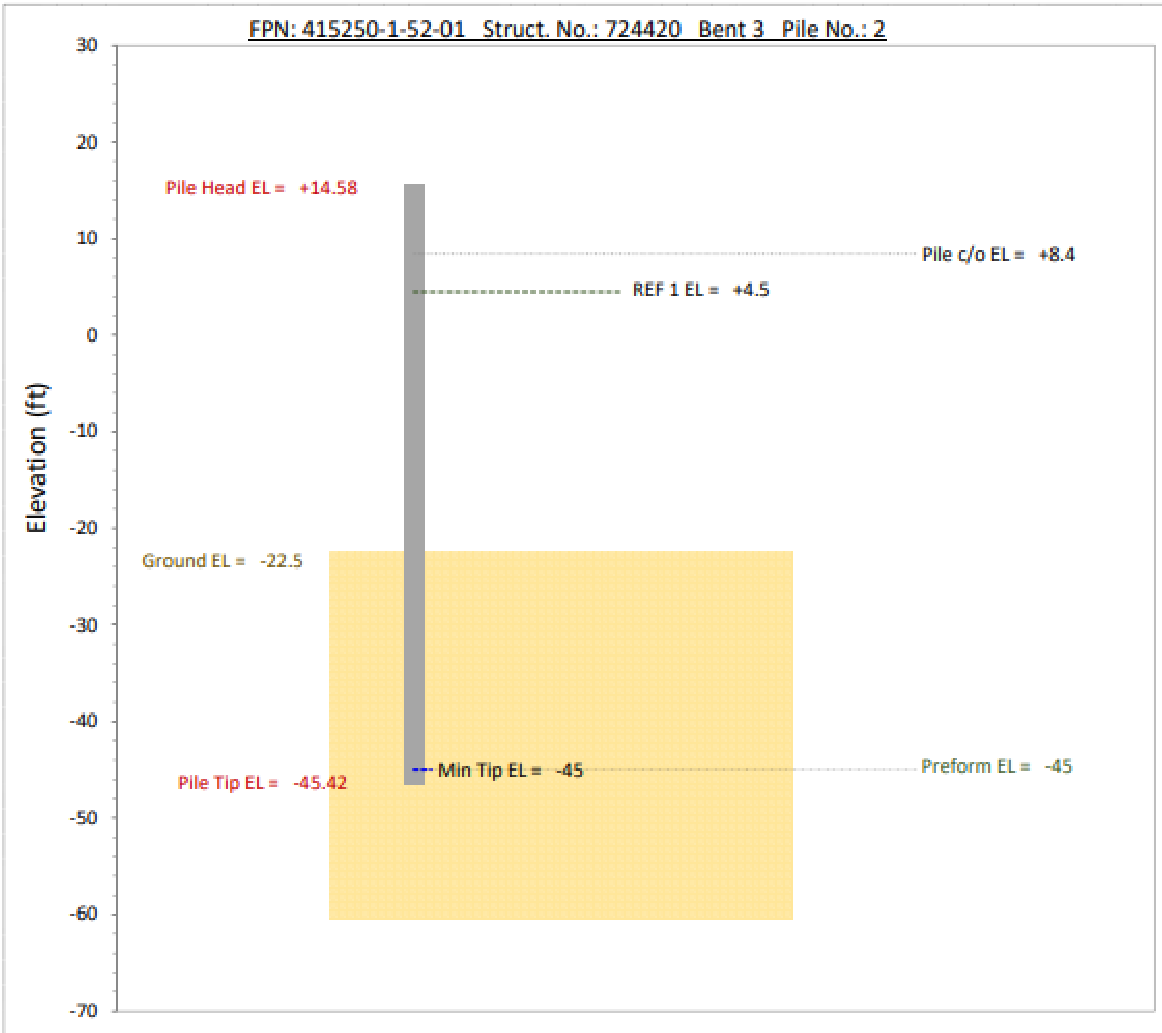
PILE DRIVING LOG

Structure No: 724420 Page No: 4 of 4

Sketch

PROJECT No: 415250-1-52-01 Bent/Pier No: 3 PILE No.: 2



PLUMB pile, as depicted in this Pile Sketch

Pile Bearing: (click on yellow shaded cell below, and select basis for Pile Bearing acceptance that applies)

Click here to select applicable bearing capacity related input: If none of the conditions below applies, type condition under which the pile was accepted.

Pile Penetration:

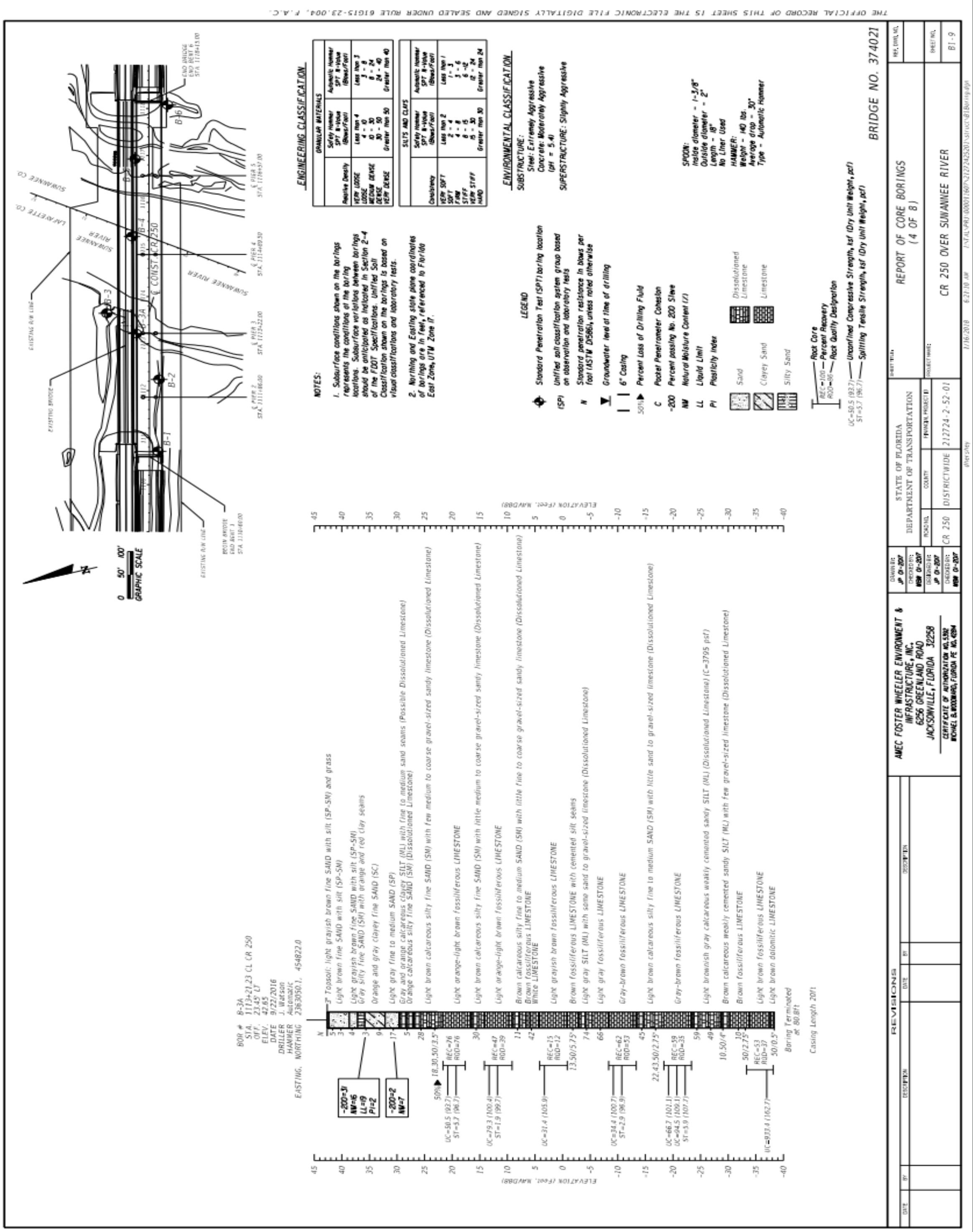
Pile Tip EL ≤ bottom EL of Preformed or Predrilled pile hole, meets 455-5 Penetration Requirements.

Current Pile Tip EL ≤ Min Tip EL in plans, meets 455-5 Penetration Requirements.

Min Tip EL is input on the log. Therefore, the 10-20 ft of penetration into firm/soft material, in accordance with 455-5 Penetration Requirements, does not apply.

Appendix C: Suwannee River Geotech Information

C.1 Suwannee River Bridge Geotechnical Boring Logs



C.2 Suwannee River Bridge Impact Driver Specifications

APE Model D62-22 Single Acting Impact Hammer

operates on diesel or bio-diesel for all types of impact pile driving

MODEL D62-22 (6.2 metric ton ram)

SPECIFICATIONS

Maximum Rated Energy	153,770 ft/lbs (208,484 Nm)
Minimum Rated Energy	78,956 ft/lbs (107,050 Nm)
Stroke at Rated Energy	11.24 ft (3.42 m)
Maximum Obtainable Stroke	12.5 ft (3.81 m)
Speed (blows per minute)	36-50

WEIGHTS (Approximate)

Piston	13,669 lbs (6,200 kg)
Anvil	2,833 lbs (1,285 kg)
Hammer Weight (includes trip device)	28,272 lbs (12,823 kg)
Hammer weight w/ DB-32 Drive Base	31,744 lbs (14,399 kg)
Typical Operating Weight w/ Drive Cap	Varies- consult factory

CAPACITIES

Fuel Tank (runs on diesel or bio-diesel)	25.89 gal (98 liter)
Oil Tank	8.32 gal (31.5 liter)

CONSUMPTION

Diesel or Bio-Diesel Fuel	5.28 gal/hour (20 liter/ hour)
Lubrication Oil	.84 gal/hour (3.2 liter/hour)
Grease	twice per day

DIMENSIONS OF HAMMER

a	Length overall	232.68 in (5,910 mm)
a	Length over cylinder extension	272 in (6,908 mm)
a	Length over trip tubes	308 in (7,823 mm)
b	Impact block diameter	27.91 in (709 mm)
c	Width over bolts	35.6 in (904 mm)
d	Hammer width overall	31.5 in (800 mm)
e	Width for guiding- face to face	32 in (812 mm)
f	Hammer center to pump guard	19.3 in (490 mm)
g	Hammer center to bolt center	15 in (381 mm)
h	Hammer depth overall	38.2 in (970 mm)
H	Minimum clearance for leads	19.7 in (500 mm)

Features

Fuel and lube pumps with 50% less parts than ICE
Hardened piston needs no high maintenance wear rings
Optional direct drive for high speed production on steel piles
Fuel pump mounted where heat will not harm it
Variable mechanical cam fuel pump- no air pistons or rings
Optional hydraulic variable fuel remote control
Heavy duty trip system for years of fault free operation
Chrome rings for super long life
Low maintenance and extremely low parts pricing
German design at a reasonable price
Two year APE warranty

AMERICAN PILEDRIVING EQUIPMENT, INC. APE

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

2/06

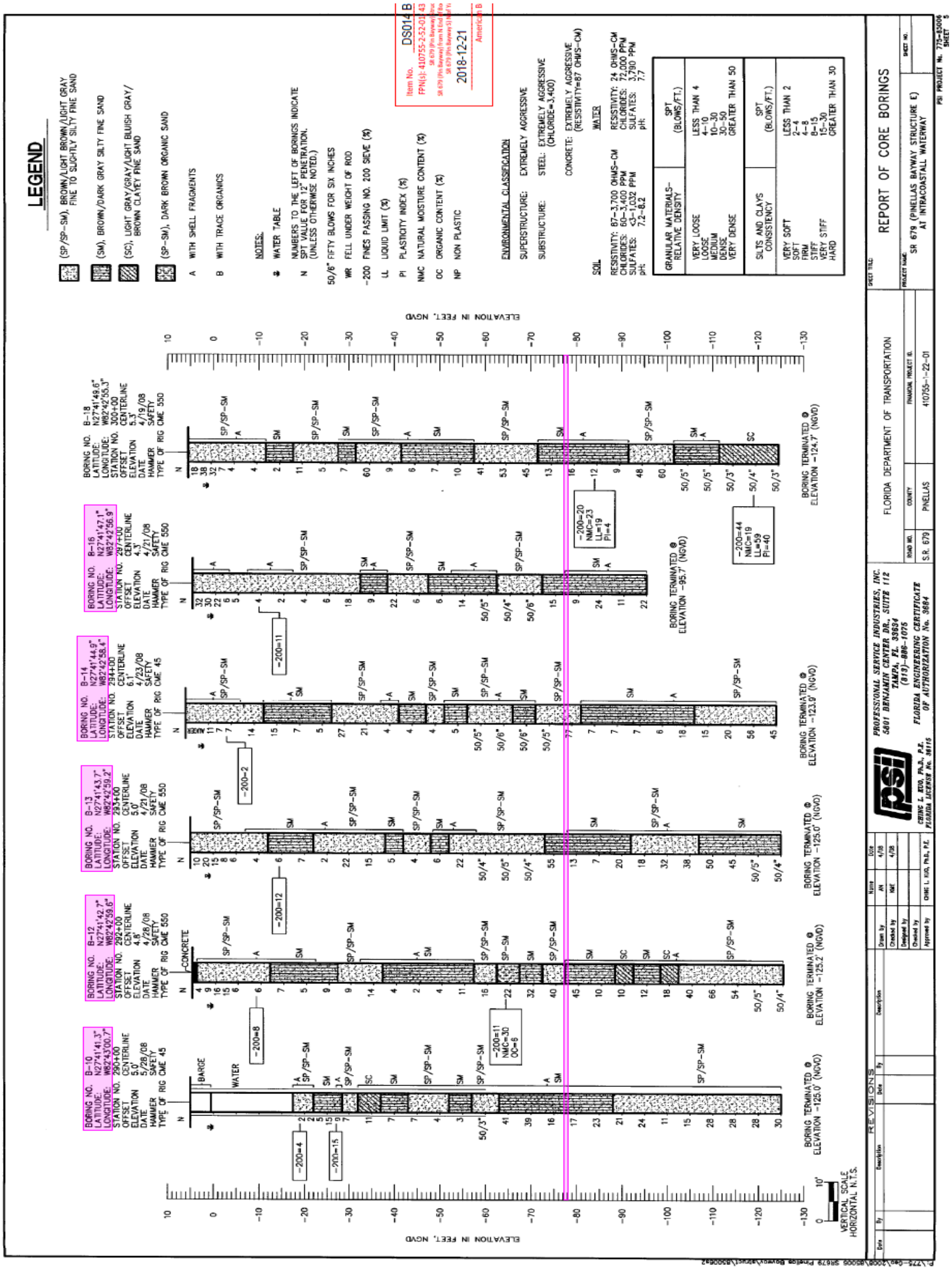
**Visit our WEB site:
www.apevibro.com
e-mail: ape@apevibro.com**

C.3 Suwannee River Pile Driving Logs

Since a construction trestle was monitored, pile driving logs were not recorded by the contractor.

Appendix D: Bayway E Geotechnical Information

D.1 Bayway E Bridge Geotechnical Boring Logs



D.2 Bayway E Bridge Vibratory Driver Specifications

APE Model 200 Vibratory Driver Extractor

The Worlds Largest Provider of Foundation Construction Equipment

SPECIFICATIONS	DATA
Eccentric Moment	4,400 in-lbs (50.69 kgm)
Drive Force	170 tons (1,513 kN)
Frequency Maximum (VPM)	0 - 1,650 vpm
Max Line Pull	133 tons (1,183 kN)
Bare Hammer Weight w/o Clamp	12,760 lbs (5,788 kg)
Throat Width	14.75 in (37 cm)
Length	104.00 in (264 cm)
Height w/o Clamp	65.50 in (166 cm)

APE Model 595 Power Unit

SPECIFICATIONS	DATA
Engine Type	Caterpillar C15 Tier III
Horse Power	595 HP (438 kW)
Drive Pressure	0 - 4,500 psi (310 bar)
Drive Flow	188 gpm (712 lpm)
Clamp Pressure	4,800 psi (69,618 bar)
Clamp Flow	10 gpm (3 lpm)
Engine Speed	2,100 rpm
Weight	19,500 lbs (8,845 kg)
Length	152 in (385 cm)
Width	82 in (208 cm)
Height	94 in (239 cm)
Hydraulic Reservoir	575 gal (2,177 L)
Fuel Capacity	160 gal (606 L)

Specifications may vary due to site conditions, specific hammer conditions or product set up.
Specifications may change without notice.
Consult the factory for details on any specific product (800) 248-8498.

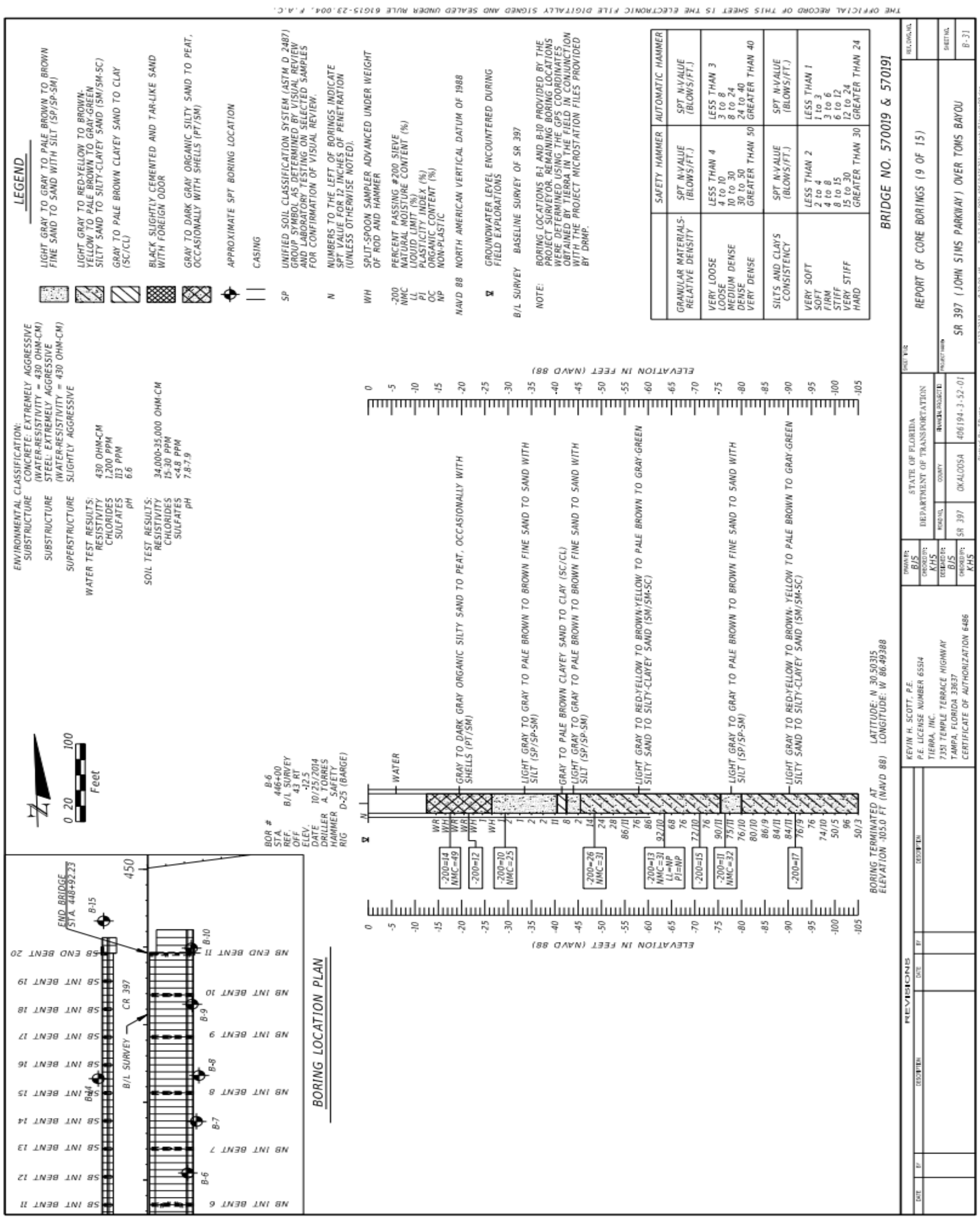
WWW.AMERICANPILEDRIVING.COM
(800) 248-8498
ape@americanpiledriving.com

D.3 Bayway E Bridge Pile Driving Logs

Since a construction trestle was monitored, pile driving logs were not recorded by the contractor.

Appendix E: John Sims Parkway Geotechnical Information

E.1 John Sims Parkway Bridge Geotechnical Boring Logs



E.2 John Sims Parkway Bridge Impact Driver Specifications

PILE EQUIPMENT INC.

BSP

BSP CX HYDRAULIC HAMMERS Specs

SPECIFICATIONS	CX50-u	CX85-u	CX110-u	CG180	CG240	CG300
RAM MASS	8800	15425	19850	26450	35265	44080
MAXIMUM IMPACT ENERGY - FT. LBS.	35000	60000	78000	132240	176320	220400
BLOW RATE @ rated energy - BPM	50	40	36	34	31	29
BASIC WEIGHT less helmet weight - LBS.	15330	22700	27600	42100	47170	57530
BASIC HAMMER LENGTH	15'-2"	16'-7"	"19'-1"	"20'-7"	"22'-9"	"24'-11"
LEADERS SIZE	"26"	"26"	"32"	"48"	"48"	"48"
OPERATING PRESSURE - PSI	3000	3400	3400	3770	4130	4200
HYDRAULIC FLOW REQUIRED - GPM	42	52	55	102	98	110

E.3 John Sims Parkway Bridge Pile Driving Logs

Excel 2013 (v 15.0): STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION 700-010-60 Construction Nov-18

PILE DRIVING LOG

Structure No: 570019 Page No: 1 of 4

PROJECT No: 406194-3-52-01 Date: 6/24/19 Station No: 446+04.23

PILE Size/Type: 18" SQ PCP Length (ft): 81.00 Bent/Pier No: IB 12 PILE No: 1

HAMMER Make/Model: BSP CX85-u S/N: 31012112/5001 Rated Energy (ft-lbs): 60,000 Operating Rate (BPM): 40

REF Elev: +8.35 (REF 2) MIN TIP Elev: -40.00 PILE CUTOFF Elev: +9.90

DRIVING CRITERIA (DC): DC2 Elev:

Type: Prod - DC #NAME?

DC Max Stk: 2.15 Min Stk req'd for PR: 2.00

Notes:

SC criteria (if applic): bpi @ ft Stk

DC1			DC2, input if applic.		
(1)	89 blows @ 1.50 ft,		(6)	blows @	ft,
(2)	67 blows @ 1.75 ft,		(7)	blows @	ft,
(3)	54 blows @ 2.00 ft,		(8)	blows @	ft,
(4)	blows @ ft,		(9)	blows @	ft,
(5)	blows @ ft,		(10)	blows @	ft,

SCOUR Elev: -15.72

PILE CUSHION Thickness & Material: 18" x 8.75" Pine Plywood

HAMMER CUSHION Thickness & Material: 23.5" x 8" Nylon

Pile Activity	Date	Start Time	Stop Time	Weather	Temp °F	Notes
Stand Pile	6/24/19	9:00 AM	9:15 AM	Cloudy	86	
DRIVE Pile	6/24/19	10:25 AM	11:59 AM	Cloudy	86	1,2,3,4,5,6

PILE DATA:

PAY ITEM No: 455-143-3 WORK ORDER No:

MANUFACTURED By: Gulf Coast Prestress MFR's PILE No: 18-18 DATE CAST: 5/17/19

TBM/BM Elev: +16.79 TBM/BM Rod Read: 6.26 H.I. Elev: +23.05

PRE-DRILLED Elev: GROUND Rod Read: GROUND Elev: -13.98

Manually input GROUND Elev (no sheet calc)

PREFORMED Elev: Bottom of Excav Rod Read: Bottom of Excav Elev:

PILE HEAD Rod Read: PILE HEAD Elev: +19.26 PILE TIP Elev: -61.11

PH Elev = REF - (LP x R) + PL = +19.26

Top of SOIL PLUG Elev (for Open Ended Pipe Piles & H-piles): Natural Ground Elev:

Input 'Natural Ground EL' ONLY when natural ground surface is below embankment/fill material. Otherwise, leave this cell BLANK

SPLICE / EACH	PREFORMED HOLE	DYNAMIC LOAD TEST	PAY SET CHECK	NO PAY SET CHECK	REDRIVE	EXTRACTION	DRIVING OF SPLICE	PILE TYPE CODE	Plumb or Batter ? (click & select) ↓ BATTER	PILE LENGTH (ft) ORIGINAL FURNISHED	PILE LENGTH (ft) TOTAL LENGTH WITH EXTENSION	Pile PENETRATION below SCOUR (ft)	EXTENSION/BUILD UP AUTHORIZED (ft)	EXTENSION/BUILD UP ACTUAL (ft)
0	0	0	0	0	0	0	0	1	8 : 1.00	74.00	74.00	45.74		

Pile PENETRATION (ft), below: GROUND: 47.5 ft SCOUR: 45.74 ft

CTQP Trainee (supervised by the Qualified Inspector) experiencing the full pile installation & log inspection: Name: Valerie Jackson

TIN: J250873657290

Qualified Inspector - I certify the Pile Driving Log content, and as applicable, the above CTQP Trainee's participation during this pile installation: Name & TIN: James Phillips / P41245382

Signature: James Phillips

DC: DC1: 89 blows @ 1.5 ft stk, 67 @ 1.75, 54 @ 2,

STATE OF FLORIDA DOT

Min Tip | 1 ft to c/o | c/o

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PILE DRIVING LOG

Page No: 2 of 4

Structure No.: 570019 | Depth Table Extended (ft): | Bent/Pier No.: IB 12 | Pile No.: 1

Depth (Input Start LP↓)	RCF		Blows	Stroke	Notes	Depth	RCF		Blows	Stroke	Notes	Depth	RCF		Blows	Stroke	Notes
53.00	1	54.00	2	0.52	BPM N/A, 1, 2,	74.00	-	75.00					-				
54.00	-	55.00	5	0.92	38	75.00	-	76.00					-				
55.00	-	56.00	3	0.9	38	76.00	-	77.00					-				
56.00	-	57.00	3	0.91	38	77.00	-	78.00					-				
57.00	-	58.00	3	0.91	39	78.00	-	79.00					-				
58.00	-	59.00	6	0.91	44	79.00	-	80.00					-				
59.00	-	60.00	6	0.92	45	80.00	-	81.00					-				
60.00	-	61.00	10	0.91	46	81.00	-	82.00					-				
61.00	-	62.00	16	0.93	47	82.00	-	83.00					-				
62.00	-	63.00	19	0.94	49	83.00	-	84.00					-				
63.00	-	64.00	15	0.94	48	84.00	-	85.00					-				
64.00	-	65.00	12	0.9	49	85.00	-	86.00					-				
65.00	-	66.00	9	0.88	49	86.00	-	87.00					-				
66.00	-	67.00	17	0.84	51	87.00	-	88.00					-				
67.00	-	68.00	20	0.89	47	88.00	-	89.00					-				
68.00	-	69.00	30	0.87	50	89.00	-	90.00					-				
69.00	-	70.00	37	0.85	50	90.00	-	91.00					-				
70.00	-	71.00	46	0.88	52	91.00	-	92.00					-				
71.00	-	72.00	32	1.44	47		-						-				
72.00	-	73.00	42	1.4	48		-						-				
73.00	-	74.00	52	1.4	48		-						-				
74.00	-	75.00	59	1.44	48		-						-				
75.00	-	76.00	68	1.45	48		-						-				
76.00	-	77.00	54	1.8	44		-						-				
77.00	-	78.00	51	1.79	44		-						-				
78.00	-	79.00	61	1.78	45, ST, 4		-						-				
67.33	2	68.00	41	1.8	45, 5		-						-				
68.00	-	69.00	69	1.8	44, DC		-						-				
69.00	-	70.00	79	1.78	45, DC, ST, 6		-						-				
70.00	-	71.00					-						-				
71.00	-	72.00					-						-				
72.00	-	73.00					-						-				
73.00	-	74.00					-						-				

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PILE DRIVING LOG

Structure No: 570019 | Page No: 3 of 4

REF inputs & Notes

PROJECT No: 406194-3-52-01 | Bent/Pier No: IB 12 | PILE No.: 1

REF No.	Input REF EL ↓	*Calculated LP values for each REF used			Input REF description (template, stringline, etc.) for each REF used: ↓
		LP min tip	LP c/o-1	LP c/o	
1	+20.02	60.49	90.19	91.19	Template / Top Roller
2	+8.35	48.73	78.43	79.43	Bottom Template / Bottom angle iron
3					
4					
5					

Standard Notes & Note No.'s 1-28

Std. Notes:	↓ = Pile Ran, F1, F2, F3, F4 = (Fuel Settings 1-4), ST = stop, CC = cushion change, HR = high rebound, TP = Test Pile, DC = Driving Criteria, PR = Practical Refusal, SC = set check, DLT = Dyn. Load Test
Note 1:	Weight of pile, pushed pile into the earth to the LP 53' (Note: Mud line EL. = -13.98)
Note 2:	Weight of hammer did not affect the LP Mark.
Note 3:	Start drive at 10:25 AM. Pile LP was at 53'
Note 4:	ST drive at 10:40 AM to remove top template so contractor could continue to drive pile.
Note 5:	Continued pile drive at 11:52 AM using pile ref. #2.
Note 6:	ST drive at 11:59 AM. Met DC.
Note 7:	
Note 8:	NOTE : The first number in the LP sheet note section, represents the Blows Per Minute.(N/A = Saximeter didn't record BPM)
Note 9:	NOTE : Axial Alignment is within tolerance as per FDOT Spec. 455-5.16.3
Note 10:	NOTE: Ground elevation was acquired with use of a weighted measuring tape from pile reference.
Note 11:	NOTE: Contractor chose to add 7' additional length to pile for their own benefit. (Authorized Production length is 74')
Note 12:	
Note 13:	
Note 14:	
Note 15:	
Note 16:	
Note 17:	
Note 18:	
Note 19:	
Note 20:	
Note 21:	
Note 22:	
Note 23:	
Note 24:	
Note 25:	
Note 26:	
Note 27:	
Note 28:	

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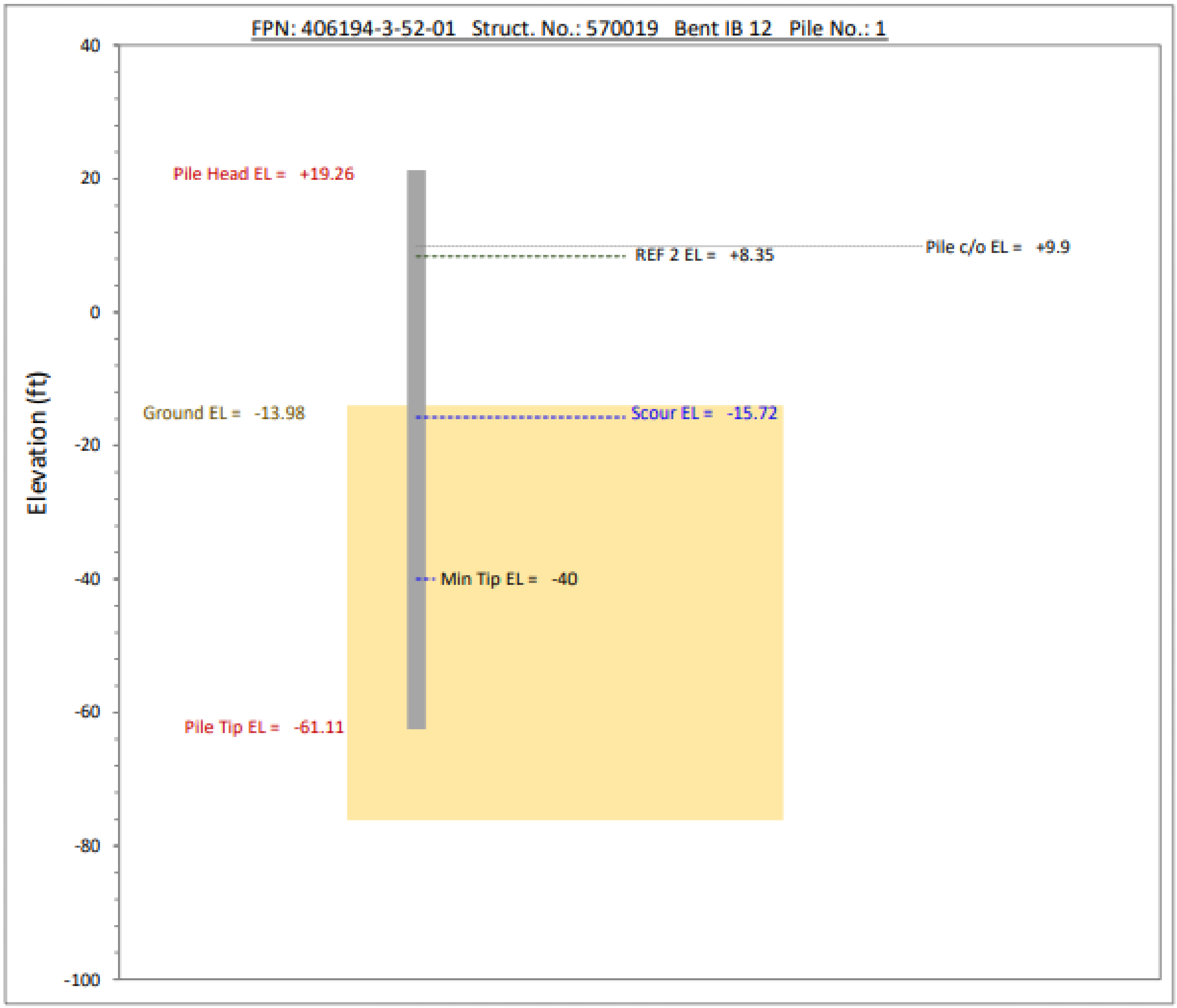
PILE DRIVING LOG

Structure No: 570019 Page No: 4 of 4
Sketch

PROJECT No: 406194-3-52-01 Bent/Pier No: IB 12 PILE No.: 1



BATTER pile - although batter is not pictorially depicted in this Pile Sketch

[Batter Ratio - Vertical : Horizontal (V : H) = 8 : 1 Calculated Batter Correction Factor R = 0.992]

Pile Bearing: (click on yellow shaded cell below, and select basis for Pile Bearing acceptance that applies)

Pile meets Driving Criteria blow count/stroke.

Pile Penetration:

Preform or Predrill EL is not yet input on the log, or does not apply.
Current Pile Tip EL ≤ Min Tip EL in plans, meets 455-5 Penetration Requirements.
Min Tip EL is input on the log. Therefore, the 10-20 ft of penetration into firm/soft material, in accordance with 455-5 Penetration Requirements, does not apply.

Vita

Jonathan Berube is a native of Chicopee, Massachusetts. He enlisted in the Navy as a Construction Electrician in October 1994. Enlisted tours include Naval Mobile Construction Battalion One, Underwater Construction Team Two, and Naval Surface Warfare Center Panama City Division. After being promoted to the rank of chief petty officer, he was selected into the Seaman to Admiral-21 (STA-21) commissioning program, where he graduated from the University of Florida with a Bachelor of Science in Civil Engineering in April 2010.

After graduation he was commissioned as a Naval Officer and reported back to Naval Mobile Construction Battalion One, where he served as Detail Officer in Charge and Liaison Officer for RC-West Afghanistan; Public Works Department (PWD) Naval Air Station Jacksonville, where he served as a construction manager and Resident Officer in Charge of Construction for the Haiti humanitarian assistance relief program; and PWD Naval Support Activity Panama City, where he served as the Facility Engineering and Acquisition Division Director.

Jonathan is qualified as a Professional Engineer (PE) in the State of Florida. He was selected into the NAVFAC Ocean Facilities Program and is a qualified Navy Diving Officer. Since August 2018, he has been a graduate student in the Master of Civil/Coastal Engineering program at the University of North Florida in Jacksonville, Florida.