Development of Noise Attenuation Coefficients Due to Underwater Pile Driving During the Design Phase

FDOT Project No. BDV34 985-03, Katasha Cornwell, Office of Environmental Management, Project Manager

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Definitions

- Decibel (dB) = $20\log_{10}\left(\frac{P}{P_0}\right)$
  - P = Pressure (Pa)
  - P_0 = Reference Pressure (1 μPa underwater; 20 μPa in air)
- Peak
  - L_{peak} (dB)= maximum sound
- Isopleth = distance at which marine organisms may be killed or injured
- Root Mean Squared Sound Level
  - P_{RMS} = $\sqrt{\frac{1}{t_2-t_1}\int_{t_1}^{t_2} P^2 dt}$
  - $L_{RMS}(\mathrm{dB}) = 20\log_{10}\left(\frac{P_{RMS}}{P_0}\right)$
- Sound Exposure Level
  - $L_{SEL}(\mathrm{dB}) = 10\,log_{10}\left(\frac{1}{t_0}\int_{t_1}^{t_2}\frac{P^2}{P_0^2}dt\right)$
- Transmission Loss
  - $TL = L_s - L_r$
    - L_s = sound at the source (or some known location)
    - L_r = sound at some range, *r*

Federal Noise Thresholds

- <u>Fish</u>
  - Physical Injury
    - $L_{peak} = 206$ dB
    - $L_{SEL} = 187$ dB for fish ≥ 2 g
    - $L_{SEL} = 183$ dB for fish < 2 g
  - Behavior
    - $L_{RMS} = 150$ dB

- <u>Sea Turtles</u>
  - Physical Injury
    - $L_{peak} = 230$ dB
    - $L_{SEL} = 184$ dB Behavior
  - Behavior
    - $L_{RMS} = 175$ dB

- <u>Marine Mammals</u>
  - Physical Injury
    - LF Certacean (baleen whales)
      - $L_{peak} = 222$ dB
      - $L_{SEL} = 183$ dB
    - HF Cetacean (some dolphins, toothed whales, beaked whales, bottlenose whales)
      - $L_{peak} = 230$ dB
      - $L_{SEL} = 193$ dB
    - VHF Cetacean (true porpoises, river dolphins, certain sperm whales, certain dolphins)
      - $L_{peak} = 202$ dB
      - $L_{SEL} = 159$ dB
    - PW Pinniped (true seals)
      - $L_{peak} = 223$ dB
      - $L_{SEL} = 183$ dB
    - OW Pinniped (sea lions, fur seals)
      - $L_{peak} = 230$ dB
      - $L_{SEL} = 185$ dB
  - Behavior
    - $L_{RMS} = 160$ dB

Federal Regulations

- How much noise are we making relative to thresholds?
- Where are we making the noise relative to a pile drive?

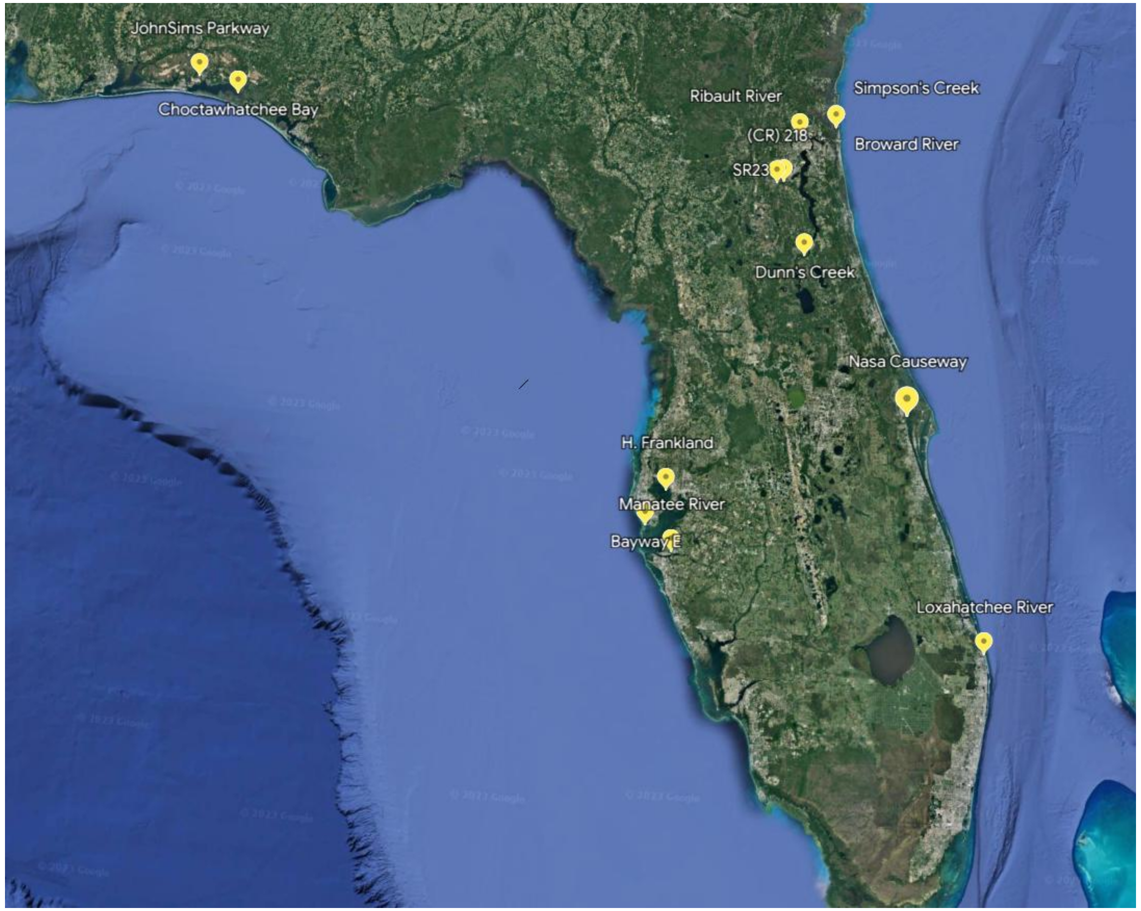
Current Procedure

- Establish a “proxy” pile
  - 158 piles included with National Marine Fisheries Service (NMFS) Pile Driving Calculator.
  - Only 29/158 (18%) of these are concrete piles.

- Compute Isopleths for each threshold
  - $TL = L_s - L_r = F \log_{10}\left(\frac{r}{r_0}\right)$
  - If F is unknown, assume F = 15; this assumption is based upon data, but notably, most data are from steel (not concrete) piles.
  - F has been shown to vary significant from as low as F = 5 to as high as F = 50 due to “other” attenuation like absorption, interaction with the water surface, and local geotechnical conditions.
  - Higher F = more attenuation = shorter isopleths.

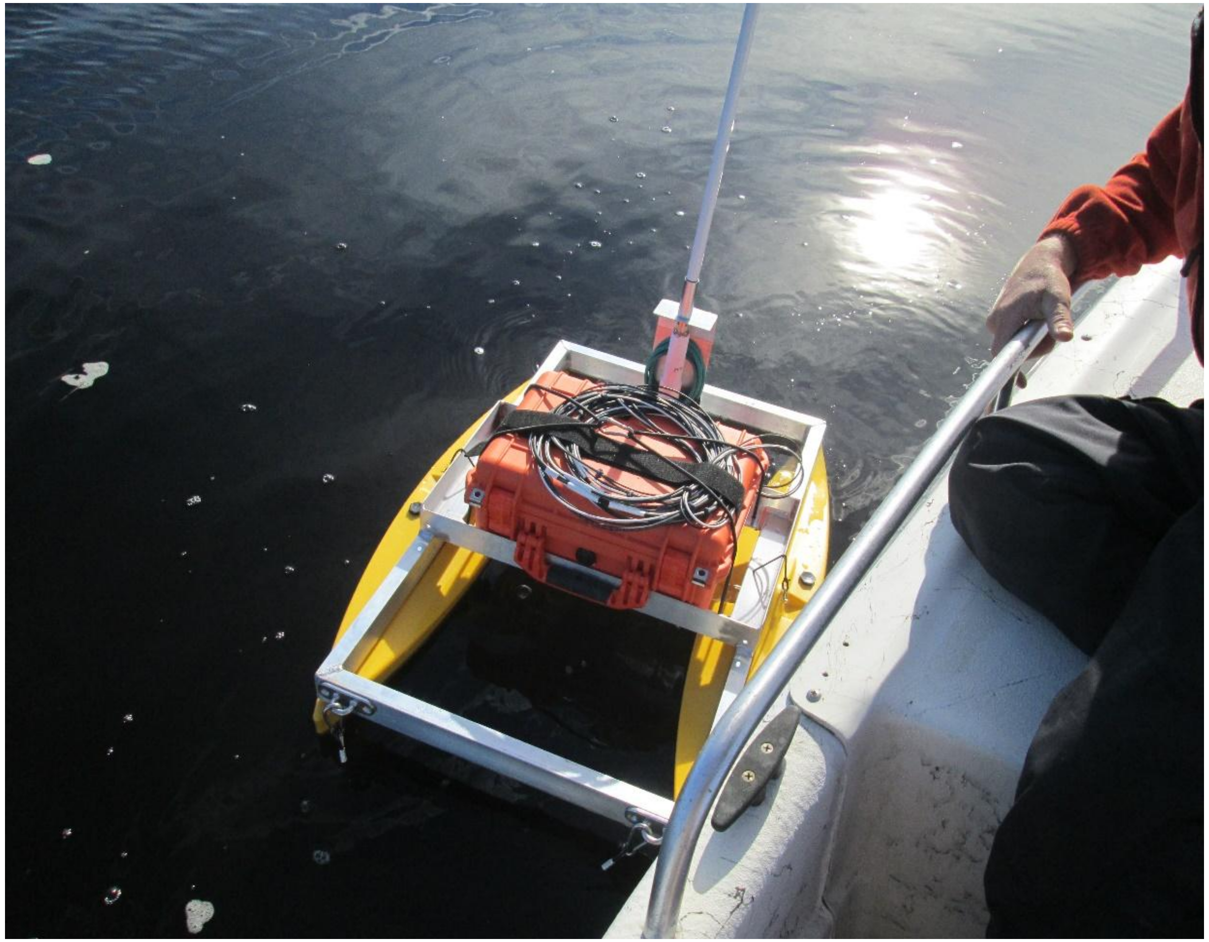
Previous Work (2018-2023)

- 84 pile drives from FL were monitored for noise using a buoy-mounted hydrophone system.
- Best-fit regression was used to assess attenuation:
  - $L_r = a\log_{10}\left(\frac{r}{r_0}\right) + b$
- Frequency domain (octave) analysis was used to establish sound frequencies.



Site Map

Data Collection – Buoy System



Data Collection Buoy

Deploying the Data Collection System

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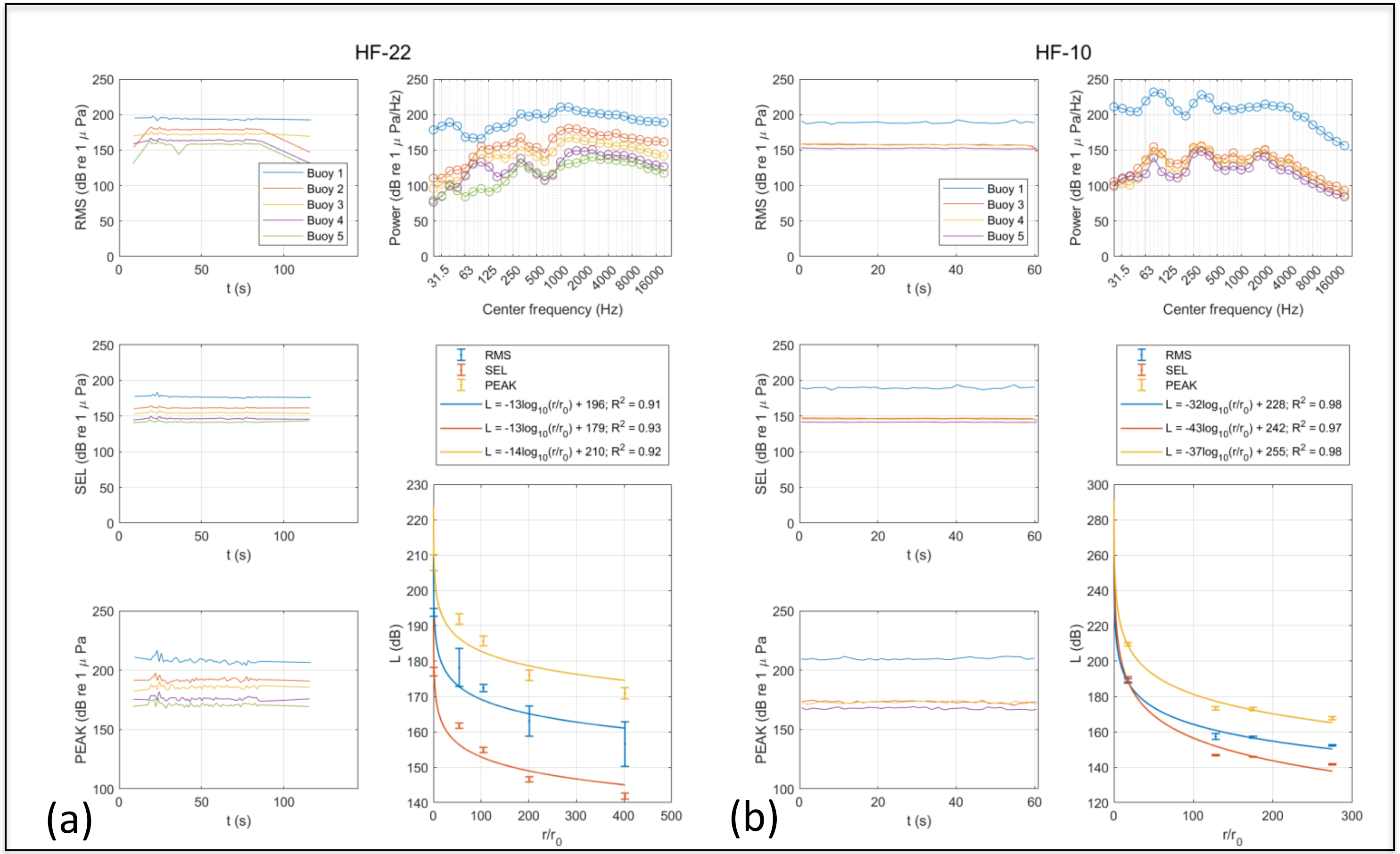
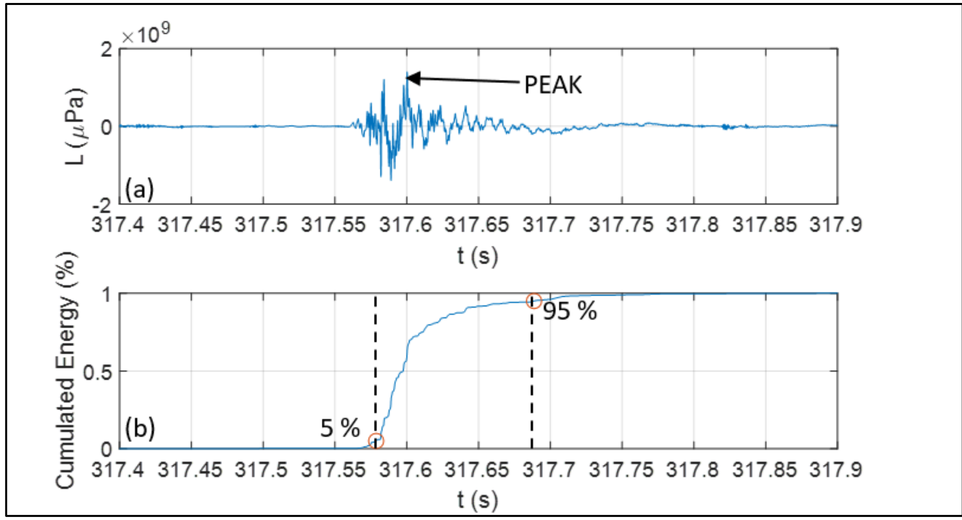
Sample Data



Sample data from the Howard Frankland Bridge showing (a) a steel pile; and (b) a concrete pile



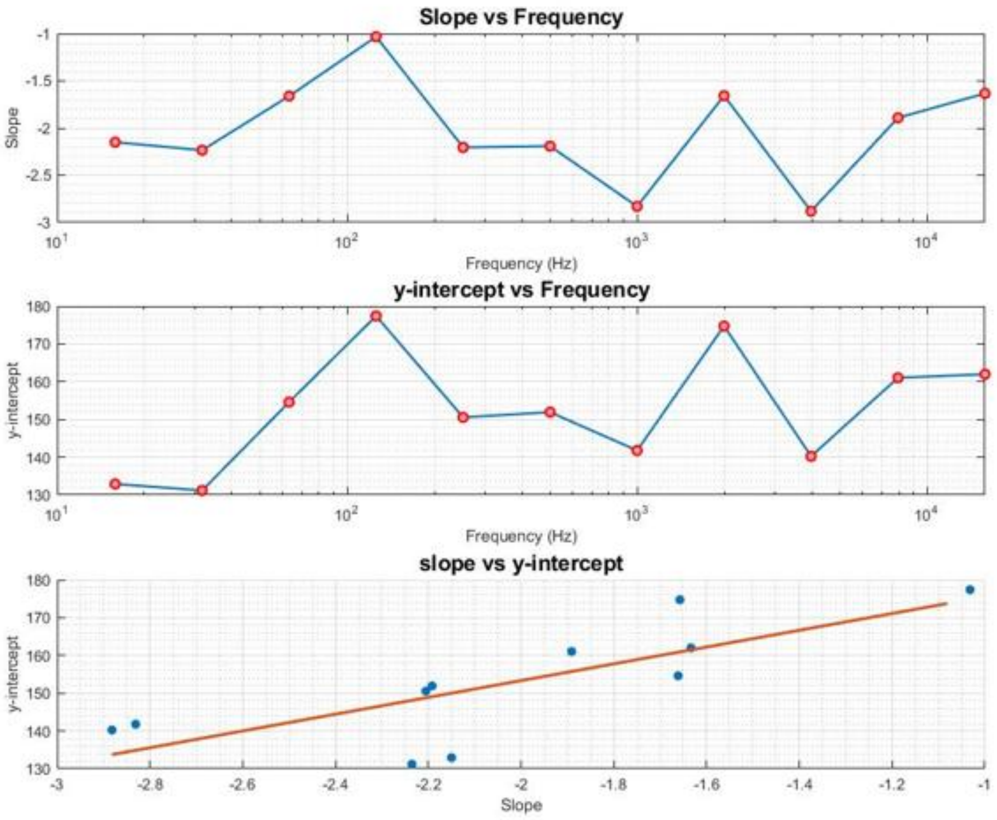
Example of sound from pile hammer blow

Development of Florida Attenuation Coefficient Tool (FACT)

- Consistently, correlated observed between *a* and *b*
  - $b = a_1 a + a_2$
  - a_1 and a_2 were further found to be correlated to frequency and <u>higher</u> at very low frequencies.

Example – suppose 200 dB in each frequency bin

Frequency (Hz)	Slope (i.e., a_1; unitless)	Intercept (i.e., a_2; dB)	F-value (i.e., a; dB)
16	2.15	133	31
31.5	2.23	131	31
63	1.68	155	27
125	1.02	178	22
250	2.2	151	22
500	2.2	153	21
1000	2.83	142	20
2000	1.65	175	15
4000	2.87	140	21
8000	1.87	161	21
16000	1.65	163	22



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Why Does This Work?

- $L_r = b + a\log_{10}\left(\frac{r}{r_0}\right)$
- $b = a_1 a + a_2$
- $a_2 = C\,a_1(f) + D$
- $b = a_1(f)a + C\,a_1(f) + D$
- $L_r = a_1(f)a + C a_1(f) + D + a\log_{10}\left(\frac{r}{r_0}\right)$
- $\boldsymbol{L_r = D + a_1(f)[C + a] + a\log_{10}\left(\frac{r}{r_0}\right)}$

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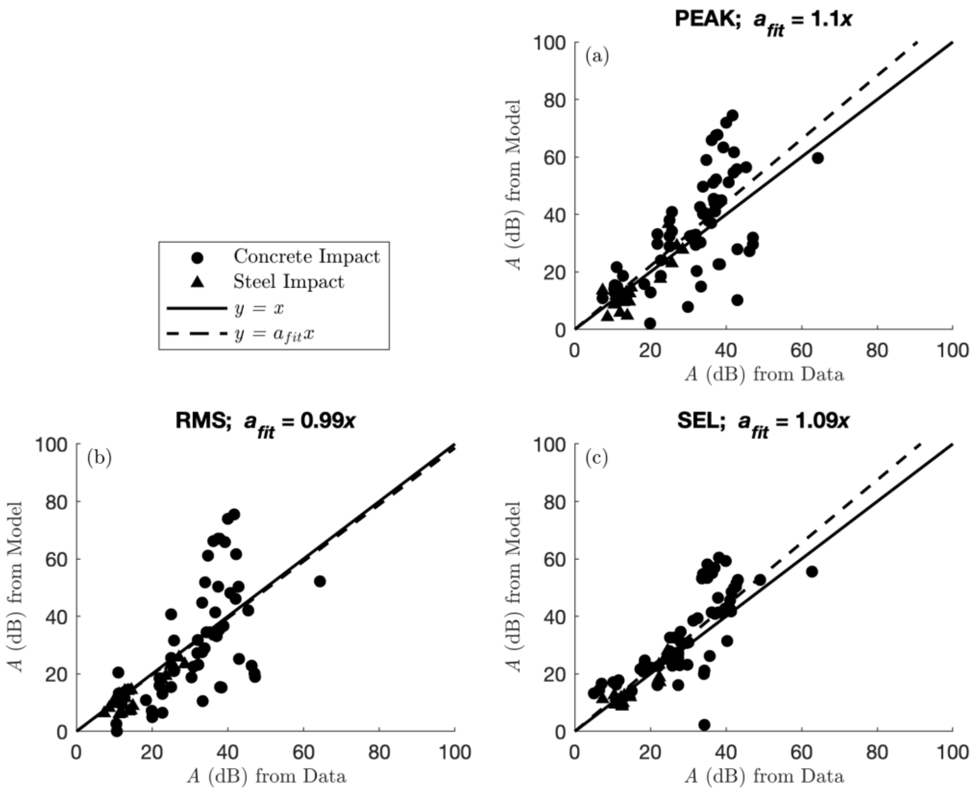
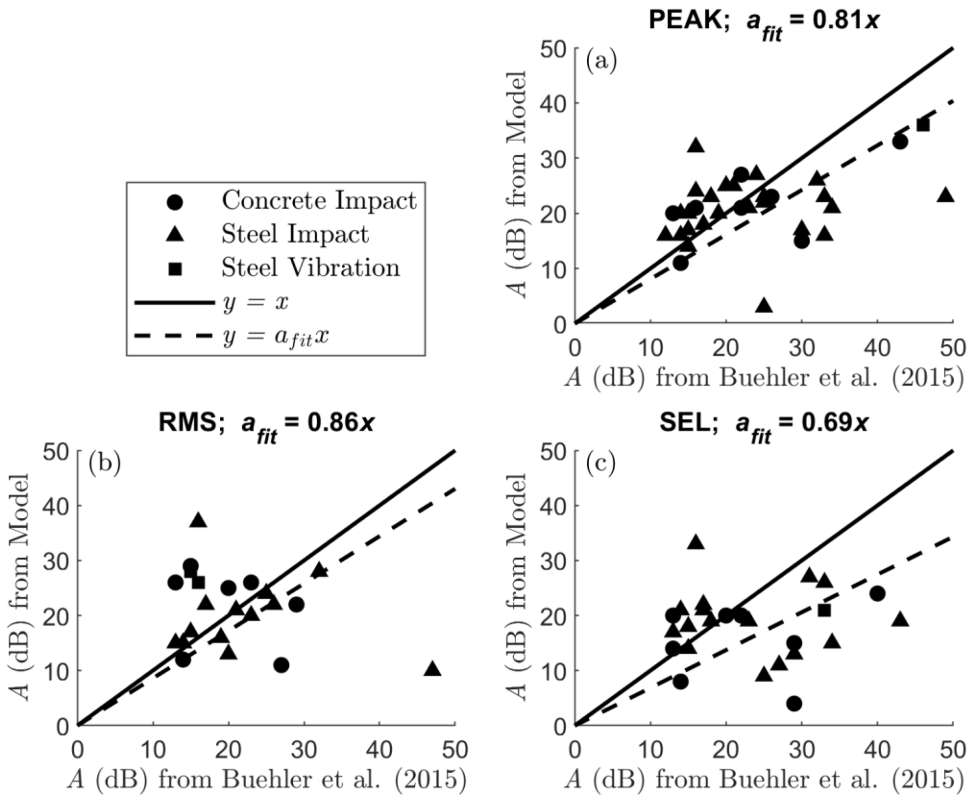
Validation



Attenuation coefficient validation via blind prediction using FL data



Attenuation coefficient validation using data reported in other sources

Example

- Suppose $L_{RMS} = 200$ dB observed at a range of 10 m from concrete pile drive?
  - $L_r = (a_1 a + a_2) - a\log_{10}\left(\frac{r}{r_0}\right)$
  - $a = \frac{200\ dB - 166.4\ dB}{2.1 - \log_{10}\left(\frac{10m}{1m}\right)} = 30.5\ \text{dB}$

- Using the 150 dB isopleth
  - $r_{FACT} = (10\ \text{m})\left[10^{\left(\frac{200\text{dB} - 150\ \text{dB}}{30.5\ \text{dB}}\right)}\right] = 436\ \text{m}$
  - $r_{NMFS} = (10\ \text{m})\left[10^{\left(\frac{200\text{dB} - 150\ \text{dB}}{15\ \text{dB}}\right)}\right] = 2{,}154\ \text{m}$

- <u>NEED TO ESTABLISH NOISE IN ONE LOCATION FIRST</u>

Best-fit coefficients for pile driving in Florida

	Steel Vibration	Steel Impact	Concrete Impact
$a_{1_{RMS}}$	1.9	2.2	2.1
$a_{1_{RMS}}$	151.6	177.8	166.4
$a_{1_{SEL}}$	1.9	2.5	2.2
$a_{2_{SEL}}$	140	145.2	141.5
$a_{1_{PEAK}}$	1.9	2.0	2.3
$a_{2_{PEAK}}$	139.6	168.1	142.8

Predicting Underwater Noise During <u>Design Phase</u>

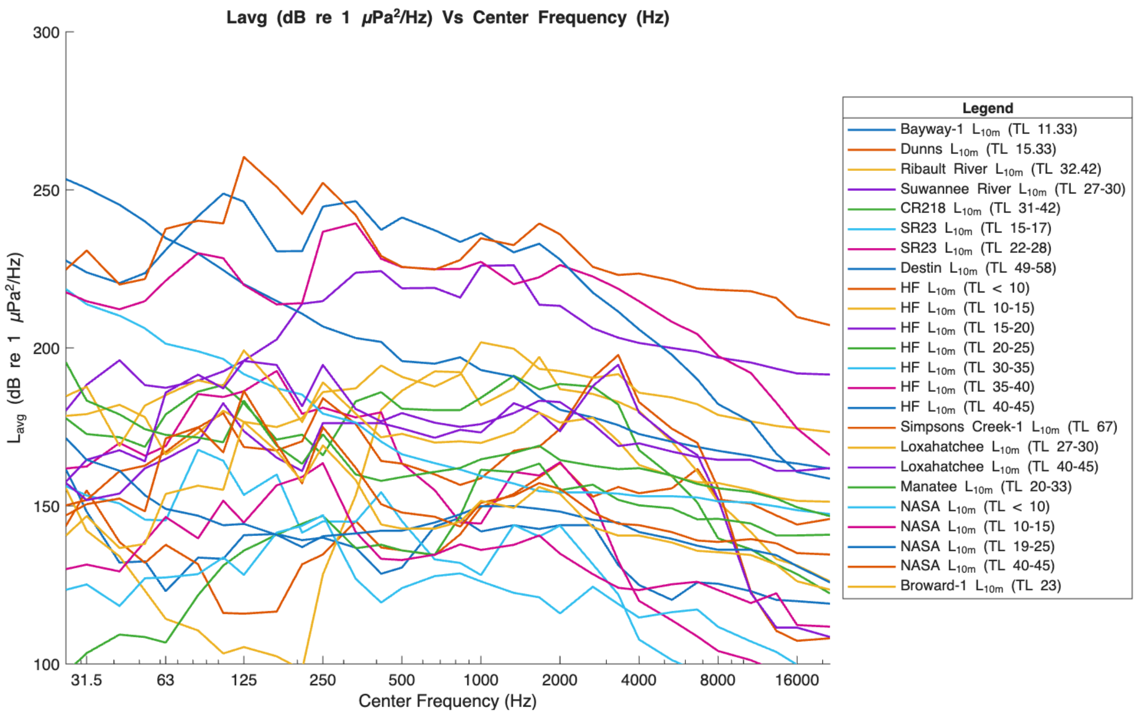
Option 1: Standard Penetration Test (SPT)

- Assess attenuation during SPT
- Develop something similar to FACT for SPT and (if needed) transfer function to get from SPT noise to FACT

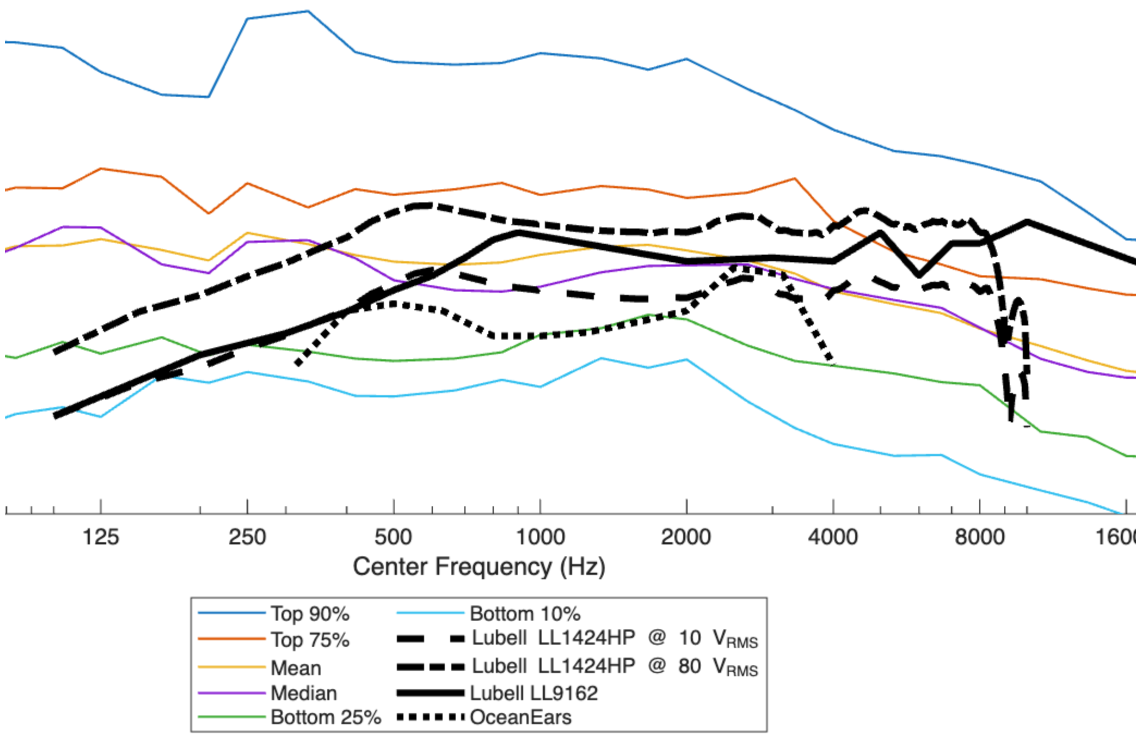
Option 2: Simulate Noise

- Use another method to generate noise
- Develop something similar to FACT for ”other method” (and transfer function, if needed).

Underwater Piezoelectric Speakers

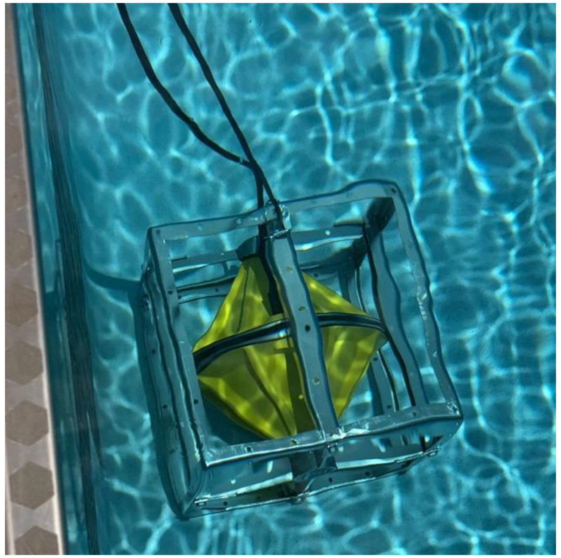


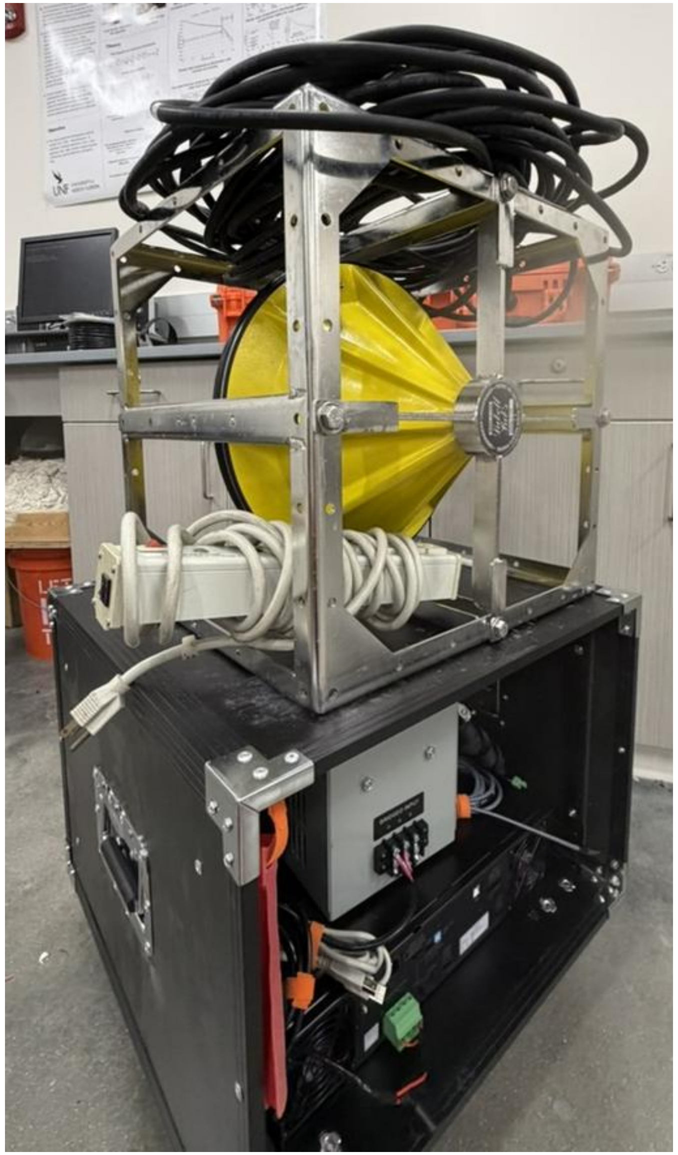
Combined broadband data from previous pile drive sound measurements in Florida



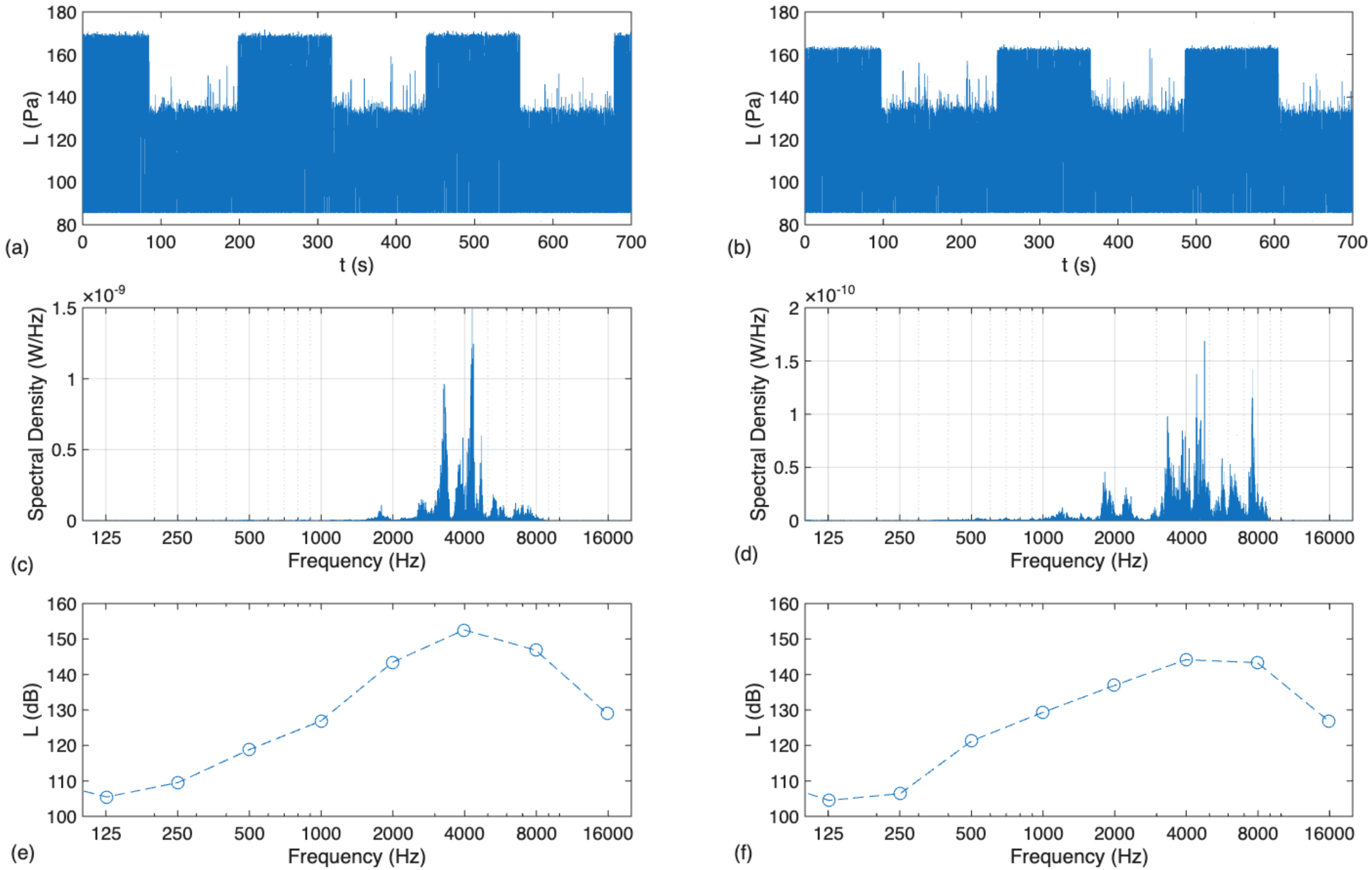
Statistics from previous pile drives overlain with commercially available underwater speaker systems

Lubell LL1424HP & Dynacord C3600FDi Amplifier





Initial Testing



Results from pool test at a range of ~25 yd showing time-series (a & b); frequency distribution (c & d); and 1/1 octave bands (e & f)

Preliminary Results

- Sound amplitude was 162 dB – 169 dB at a range of 25 yd; this corresponds to between 183 dB and 190 dB at 10 m. <u>This should be loud enough to assess attenuation in the field</u>.

- Data suggest dominant frequencies between 3 kHz and 6 kHz, although the system is still loud from 1 kHz to 10 kHz. <u>It may be better to experiment with getting better lows</u>.

Upcoming/Ongoing Work

- Additional pool tests
  - Experiment with different tones.
  - Experiment with all hydrophones at different ranges to establish sound decay in the pool.

- Field testing in intracoastal waterway

- Field testing with SPT

Thank you for Supporting this Research!