Underwater Noise Level Study during Impact Pile Driving

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

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Presentation Outline

- Background Information
- Objectives
- Research Tasks
- Summary of Research Conclusions
- Recommendations
- Project Benefits
- Implementation Items
- Publications
- Equipment
- Closing Slide/Page

Background Information

- Pile driving may make enough noise to kill/injure fish and other marine animals

- Florida does not have reliable local guidelines to predict anthropogenic noise during pile driving and it has been using CalTrans' "Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish" (Buehler et al. 2015)

- California guidelines were based mostly upon percussion driving steel piles. On Florida bridges, most drives are percussion drives with concrete piles or vibratory drives with steel piles.

Project Objectives

- Main Objective – Characterize underwater noise levels during impact pile driving throughout the State of Florida using Florida-specific conditions. In particular:
  - Florida geotechnical conditions
  - Understand the difference between concrete percussion drives, steel percussion pile drives, and steel vibratory drives

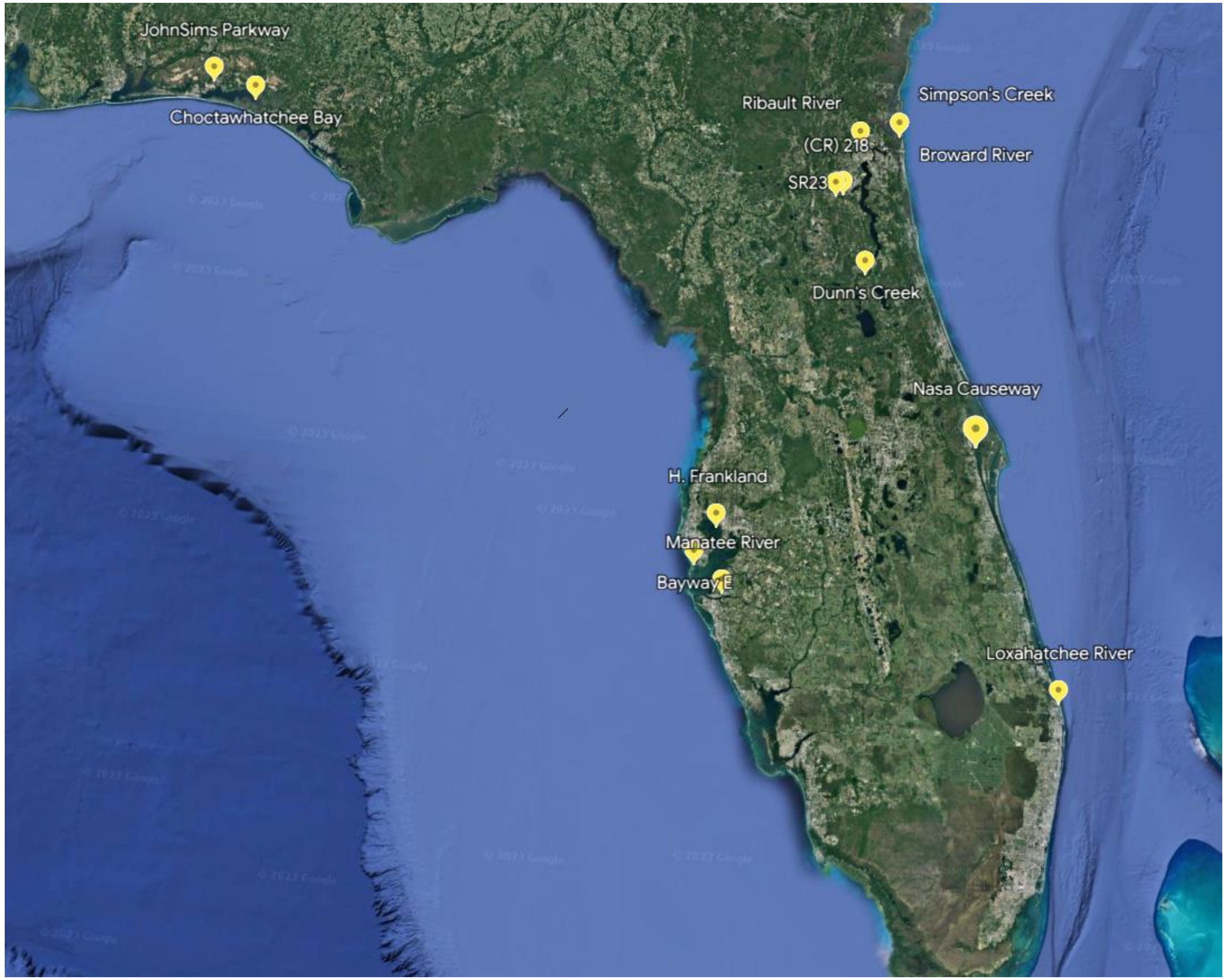
Task 1 – Kickoff Teleconference

- Completed in May 2018

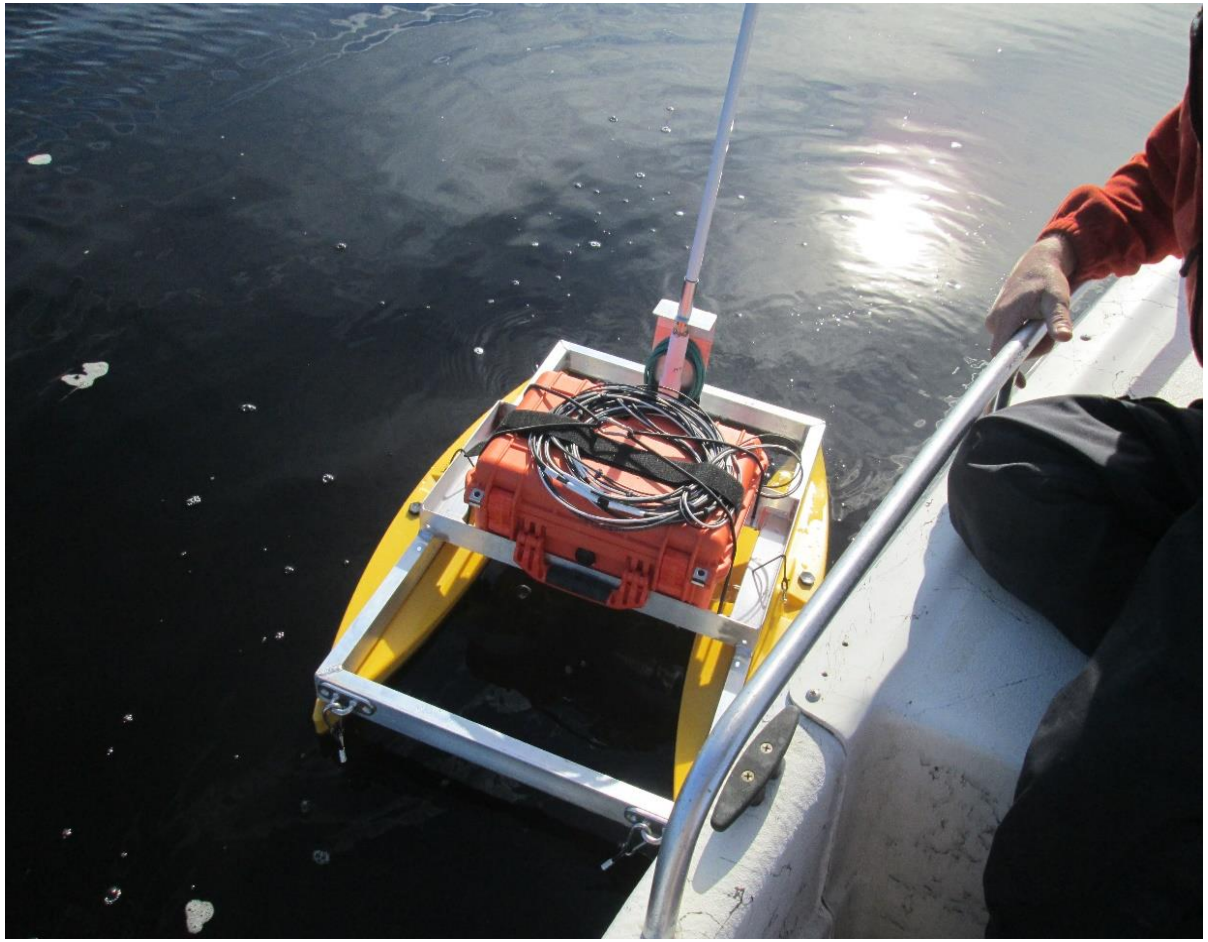
Tasks 2 – Field Data Collection

- Completed May 2018 through February 2023
- Data consisted of 91 drives from 13 sites
  - 70 square precast concrete piles ranging from 18 inches to 36 inches
  - 5 vibratory drives w/ 18-inch sheet pile and 36-inch steel pipe
  - 16 steel impact drives on H-piles

Site Locations



Data Collection – Buoy System



Data Collection Buoy

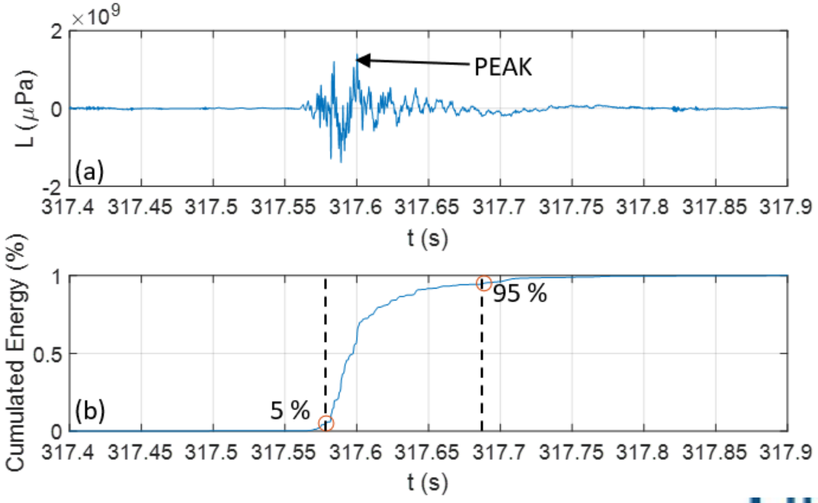
Deploying the Data Collection System

Task 3 – Data Analysis

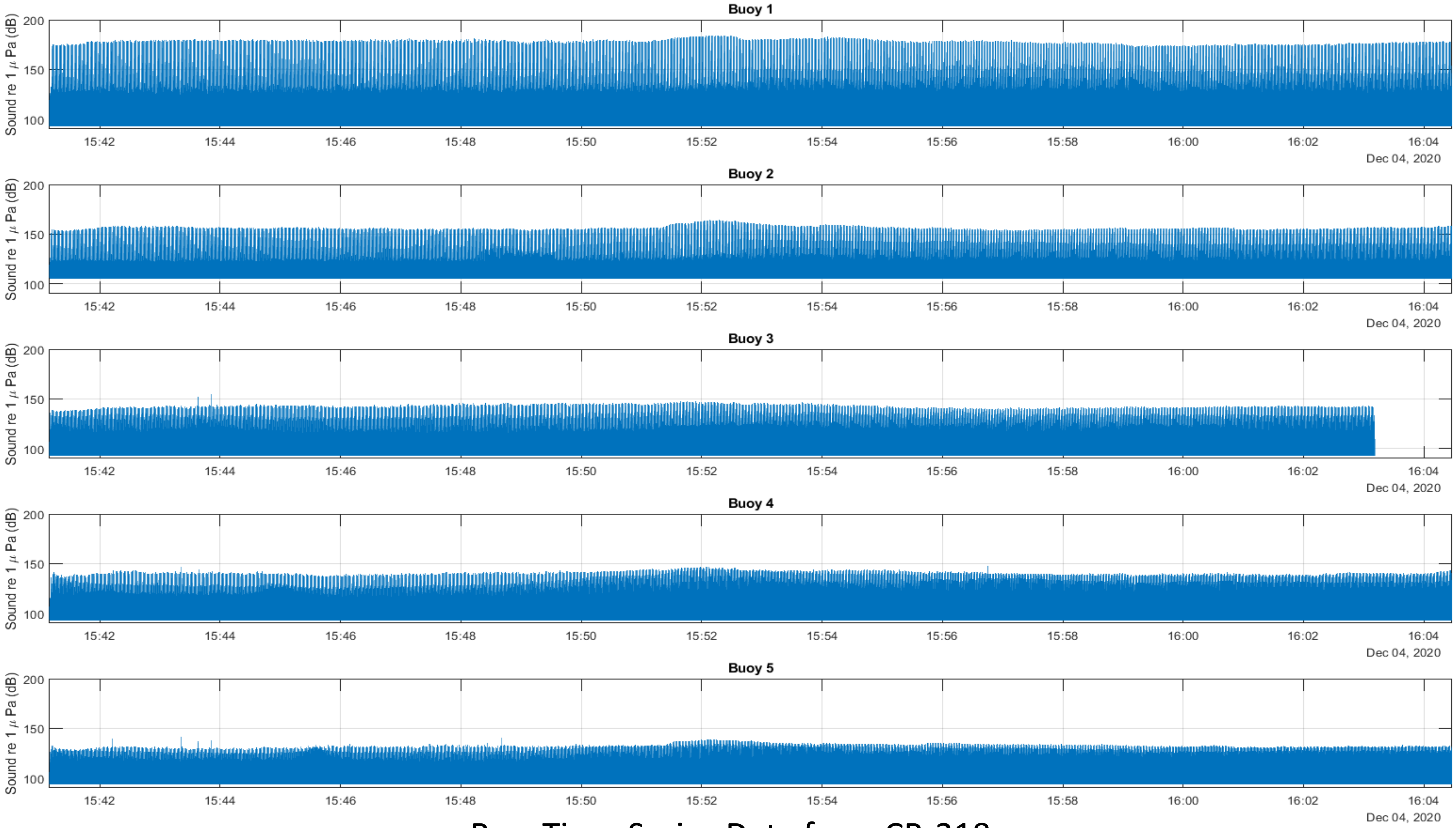
- Decibels
  - $dB = 10\log_{10}\left[\left(\frac{P}{P_{ref}}\right)^2\right]$
  - $P =$ sound pressure (Pa)
  - $P_{ref} = 1\mu$Pa
- Sound Attenuation Coefficient
  - $TL = F\log_{10}\frac{R}{R_0}$
  - *R* = Range from sound source
  - R_0 = Reference range
  - *F* = Transmission loss coefficient. According to NMFS, *F* = 15
  - *TL* = Transmission loss (in dB)

- Sound Statistics
  - *Peak* = maximm sound-level
  - *RMS* = root-mean-square sound-level
  - *SEL* = sound exposure level

$$SEL = 10\log_{10}\int\left(P/P_{ref}\right)^2 dt$$

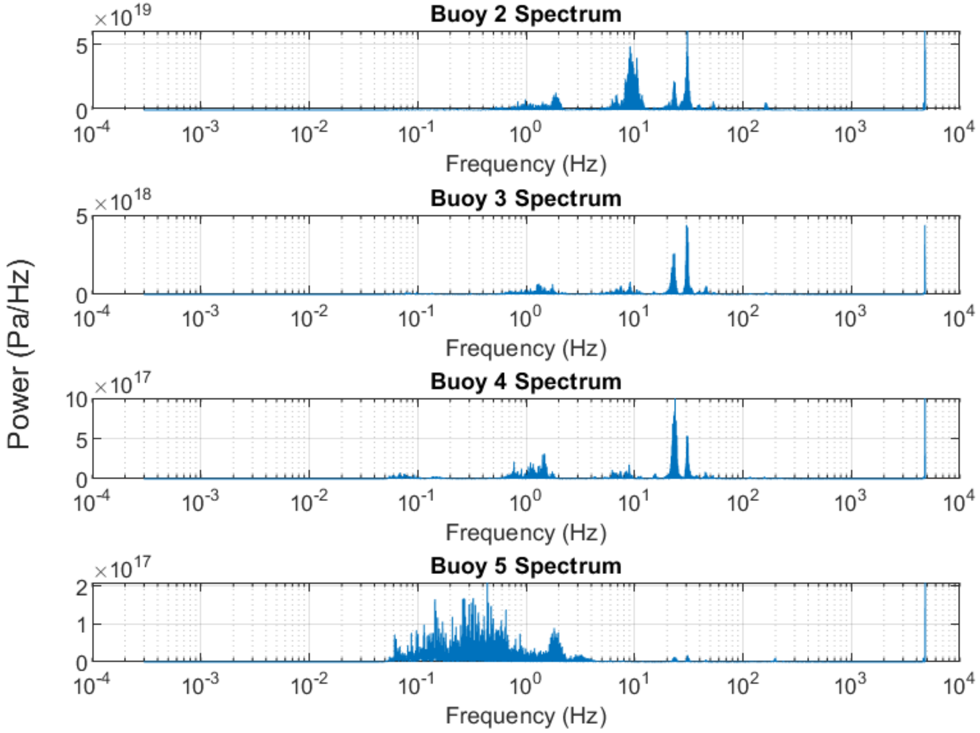


Task 3 – Data Analysis

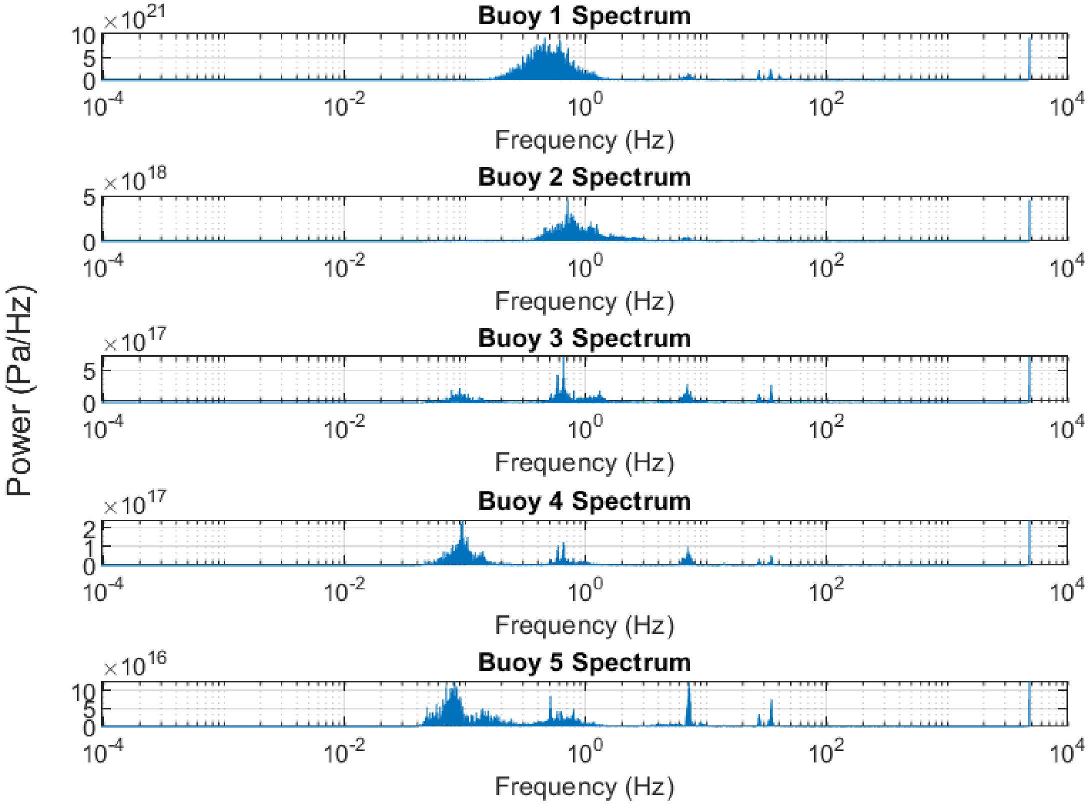


Raw Time-Series Data from CR-218

Sample Frequency Data – Howard Frankland



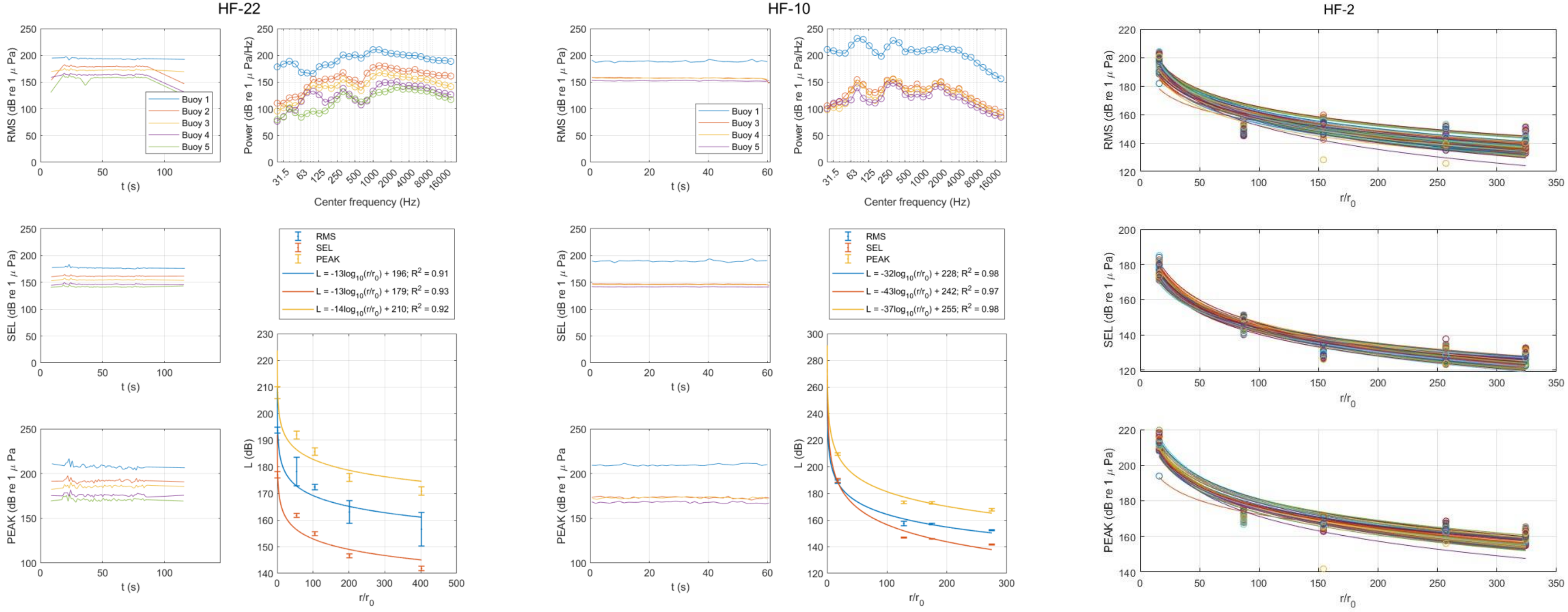
Spectral data from Howard Frankland East
(Steel King Piles)



Spectral data from Howard Frankland West
(Concrete Piles)

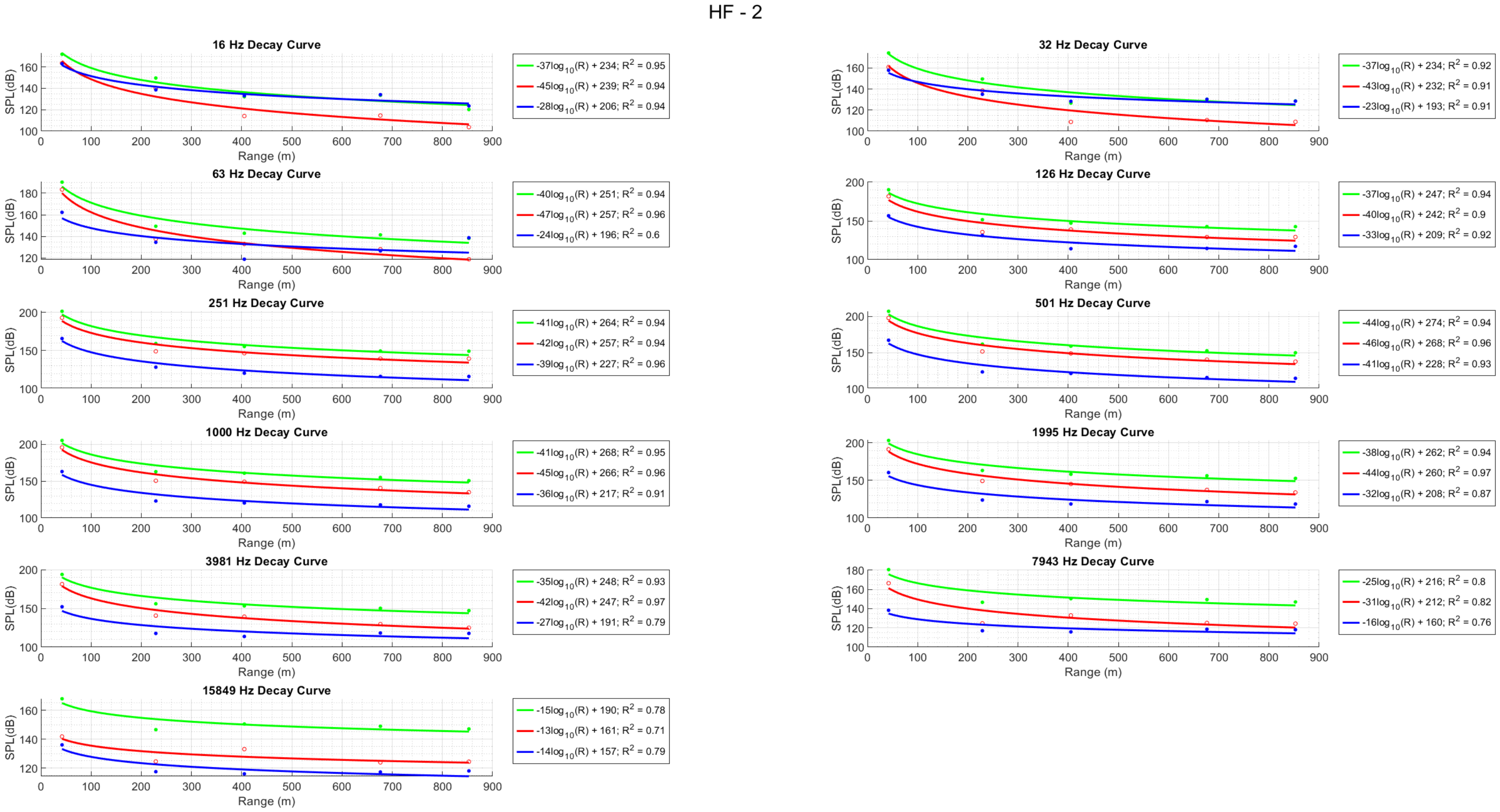
Examples of Spectral Data from the Howard Frankland Bridge

Single-Strike and Blow-by-Blow Sound Decay Curves



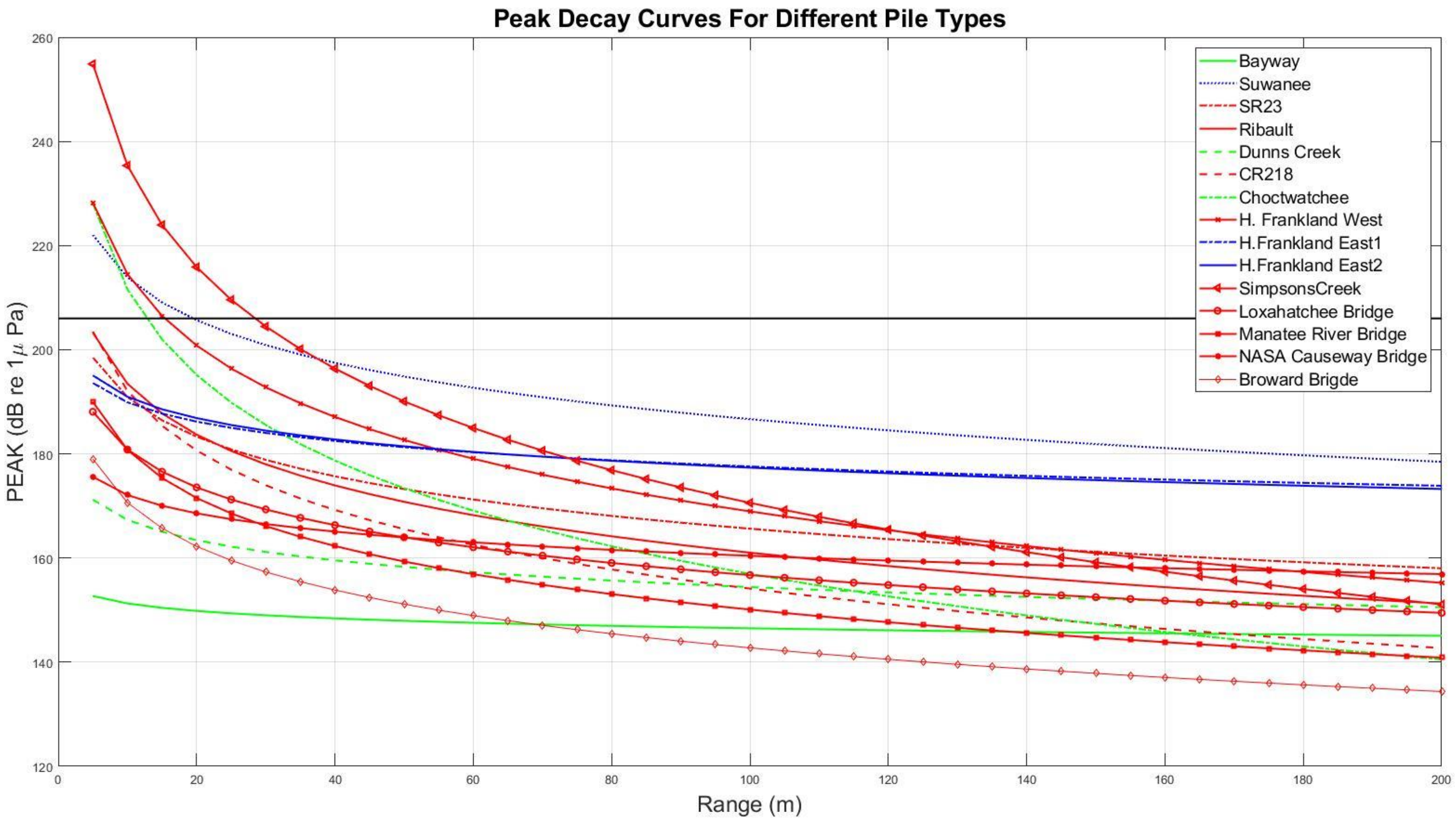
Examples of single-strike averaged data (left and middle) and blow-by-blow data (right)

1/1 Octave Decay Curves



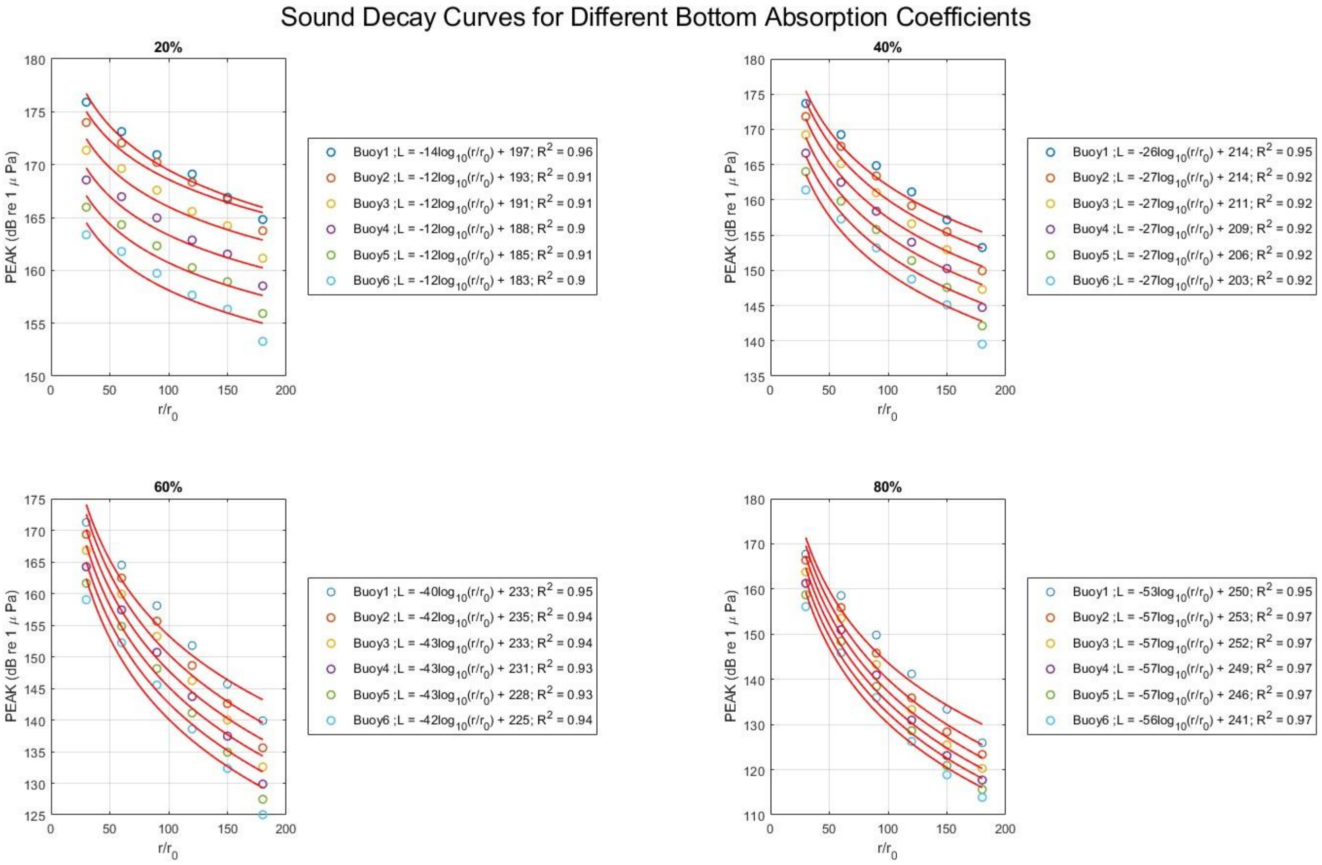
Examples of Peak Octave Decay Curves

Decay Curve Variability



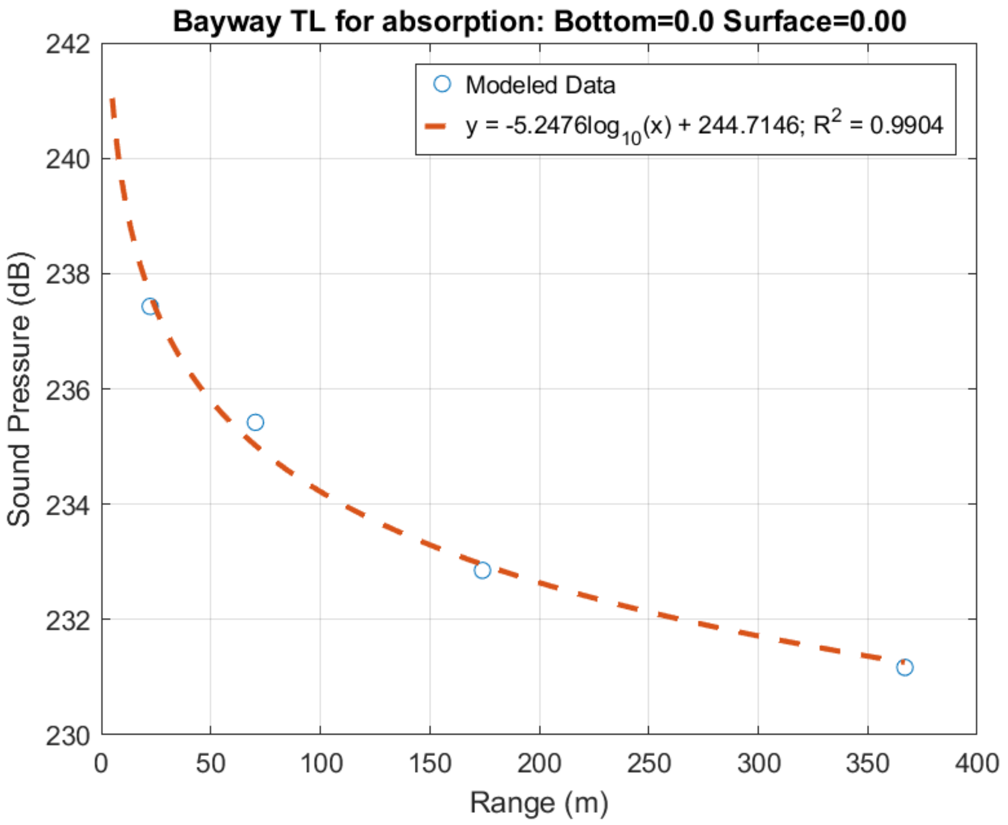
Mean Decay Curves from All Sites

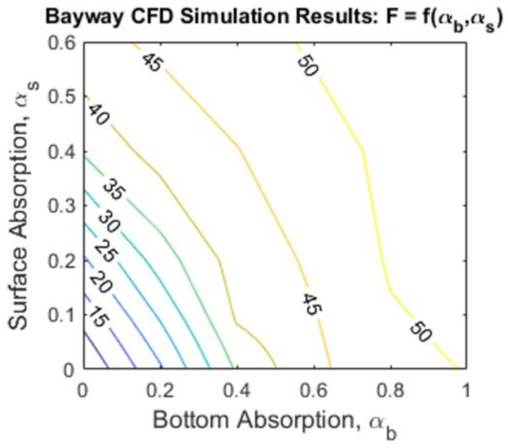
CFD Hypothetical Data



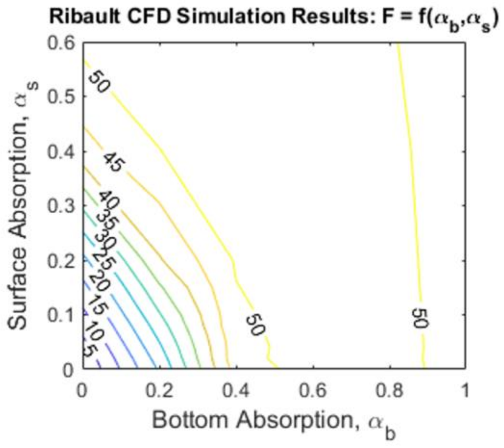
Example of CFD Hypothetical Data

CFD Data using Local Bathymetry



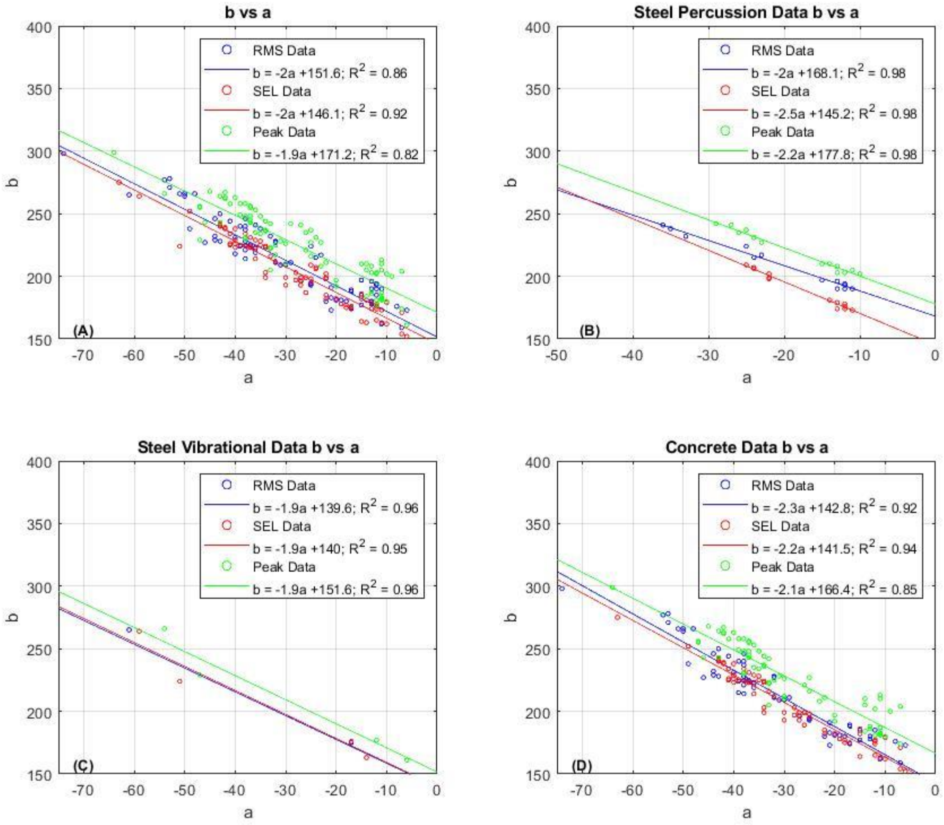


(a)



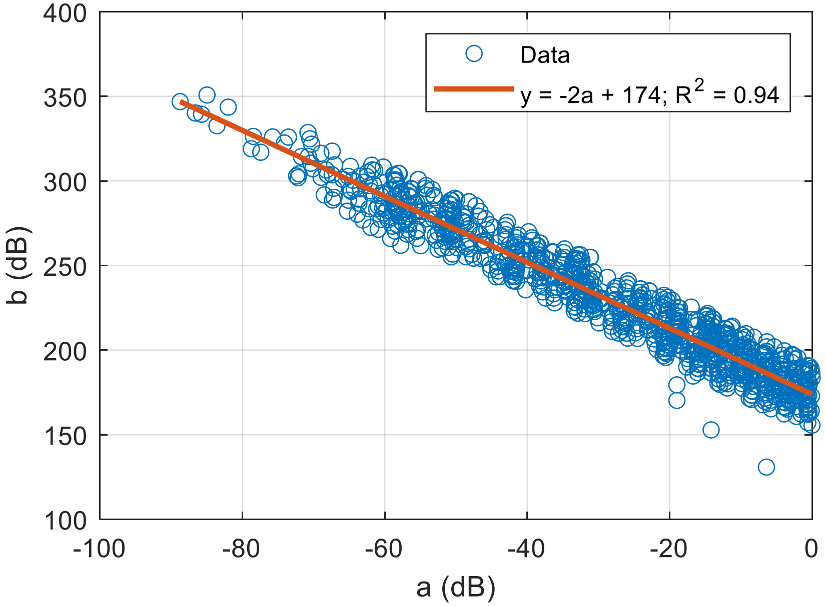
(b)

Development of the Florida Attenuation Coefficient Tool (FACT)

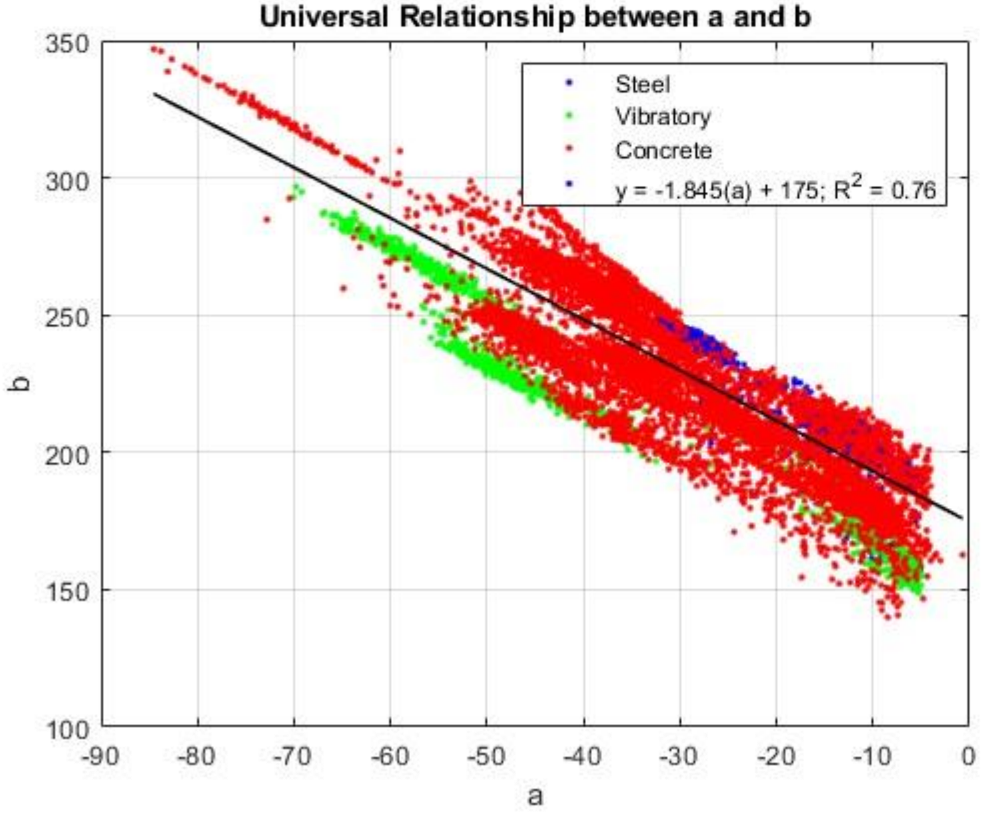


- $L_r = b + a\log_{10}\left(\frac{r}{r_0}\right)$
- F = -a; b = $L_s - B$
- $b = a_1 a + a_2 \rightarrow L_r = a_1 a + a_2 + a\log_{10}\left(\frac{r}{r_0}\right)$
- Example - $L_s = 220\ dB$ @ 10 m; threshold = 206 dB; concrete pile
  - Using NMFS
    - F = 15 dB
    - $r = \left\{10^{\left[\frac{L_m - L_r}{F}\right]}\right\} r_m = \left\{10^{\left[\frac{220\ dB - 206\ dB}{15\ dB}\right]}\right\} 10\ m = 86\ m$
  - Using FACT
    - $-a = F = \frac{L_m - a_2}{a_1 - \log_{10}\left(\frac{r}{r_0}\right)} = \frac{220\ dB - 166.4\ dB}{2.1 - \log_{10}(10\ m/1m)} = 49\ dB$
    - $r = \left\{10^{\left[\frac{L_m - L_r}{F}\right]}\right\} r_m = \left\{10^{\left[\frac{220\ dB - 206\ dB}{49\ dB}\right]}\right\} 10\ m = 19\ m$

Is the FACT Universal?

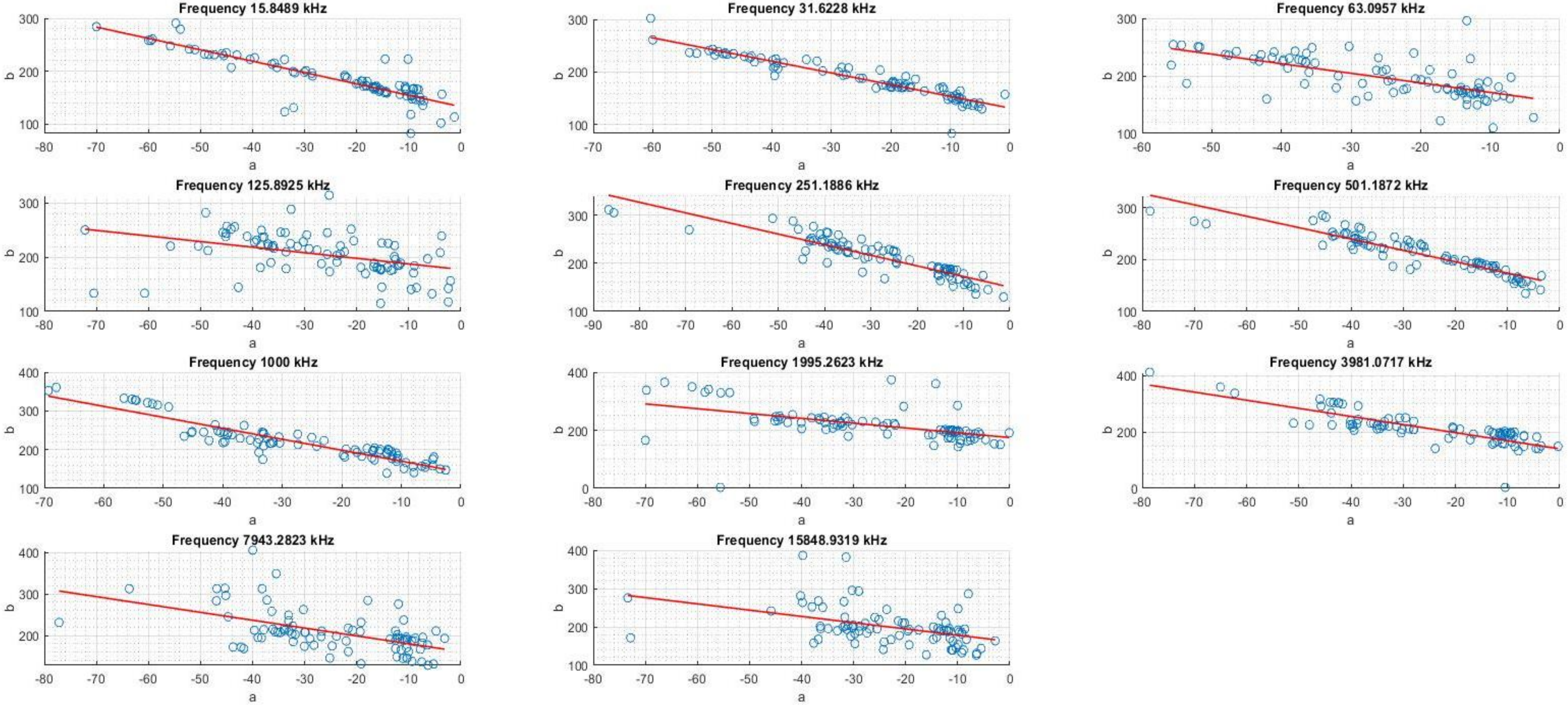


a and *b* from all hypothetical data



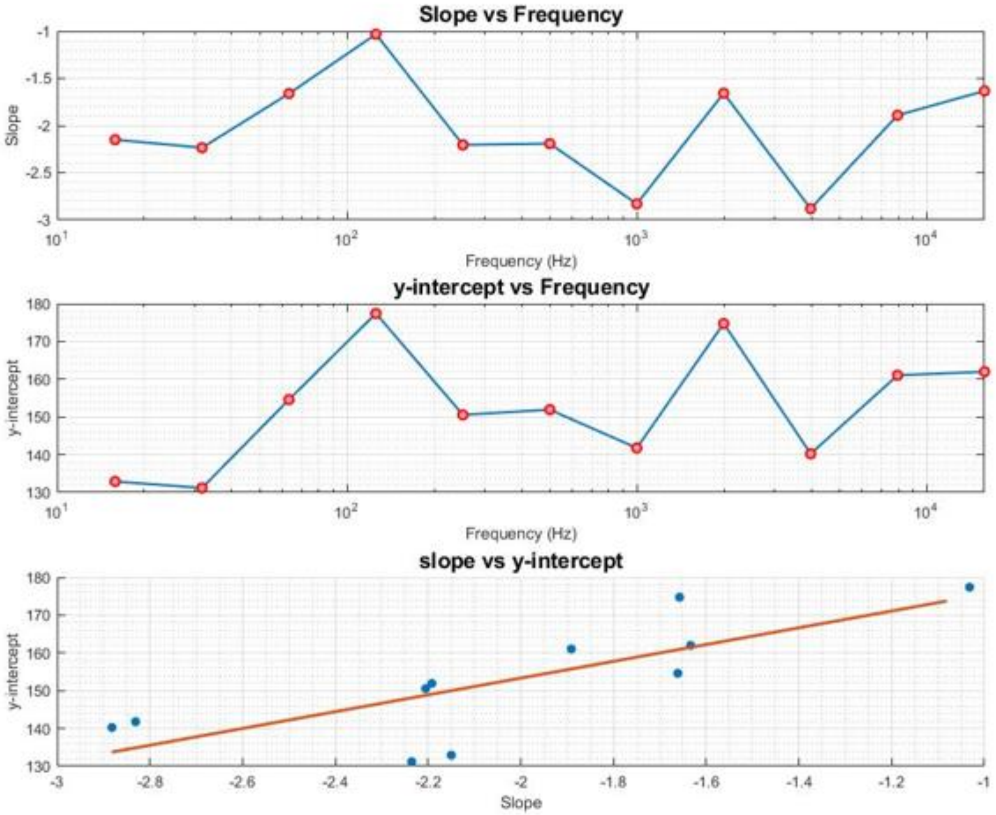
a and *b* from all blow-by-blow data

Is the FACT Universal?



a and *b* in each frequency bin

Why is the FACT Universal?



Attenuation and source-levels as functions of frequency

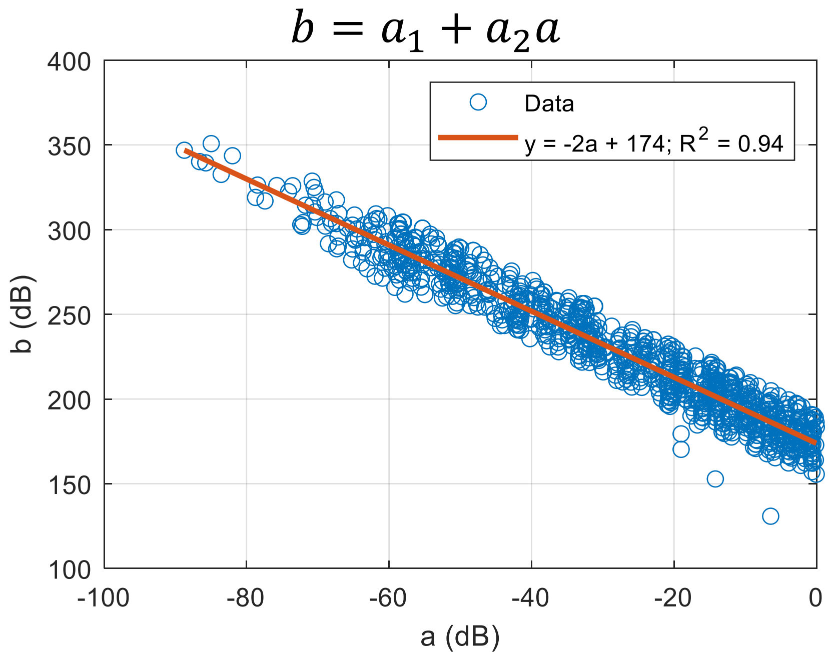
Example – suppose 200 dB in each frequency bin

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

Why is the FACT Universal?

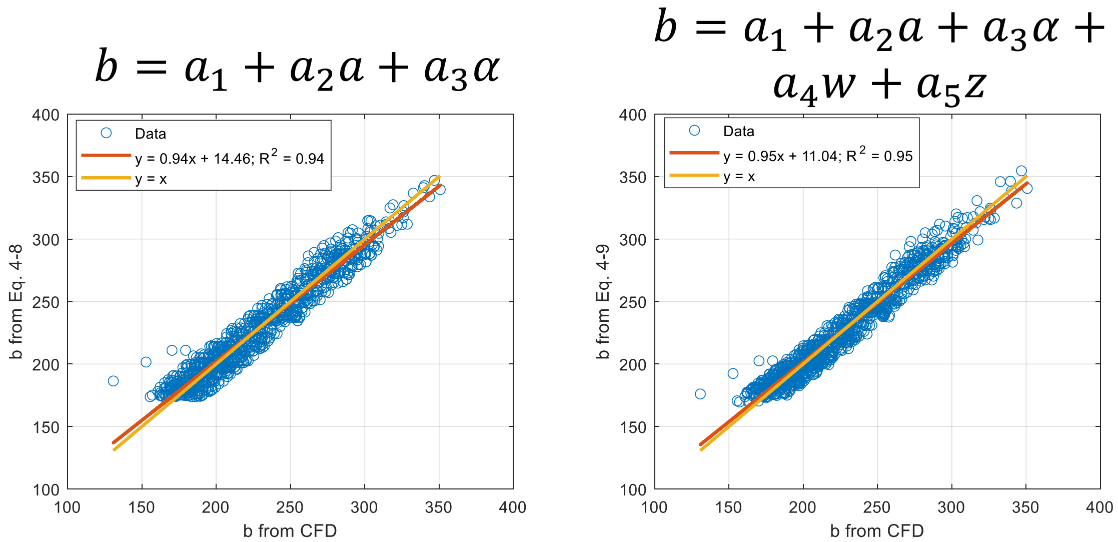
- $L_r = b + a\log_{10}\left(\frac{r}{r_0}\right)$
- $b = a_1 a + a_2$
- $a_2 = C\,a_1(f) + D$
- $b = a_1(f)a + C\,a_1(f) + D$
- $L_r = a_1(f)a + Ca_1(f) + D + a\log_{10}\left(\frac{r}{r_0}\right)$
- $L_r = D + a_1(f)[C + a] + a\log_{10}\left(\frac{r}{r_0}\right)$

Do Including Water Depth, Geotech Absorption, or Channel Width Improve Predictive Value?



$$b = a_1 + a_2 a$$

Hypothetical CFD data relationship between *a* and *b* using hypothetical CFD data



$$b = a_1 + a_2 a + a_3 \alpha$$

$$b = a_1 + a_2 a + a_3 \alpha + a_4 w + a_5 z$$

Modeled *b* data including geotech (left) and water depth + geotech + channel width (right) using hypothetical CFD data

w = channel width

z = water depth

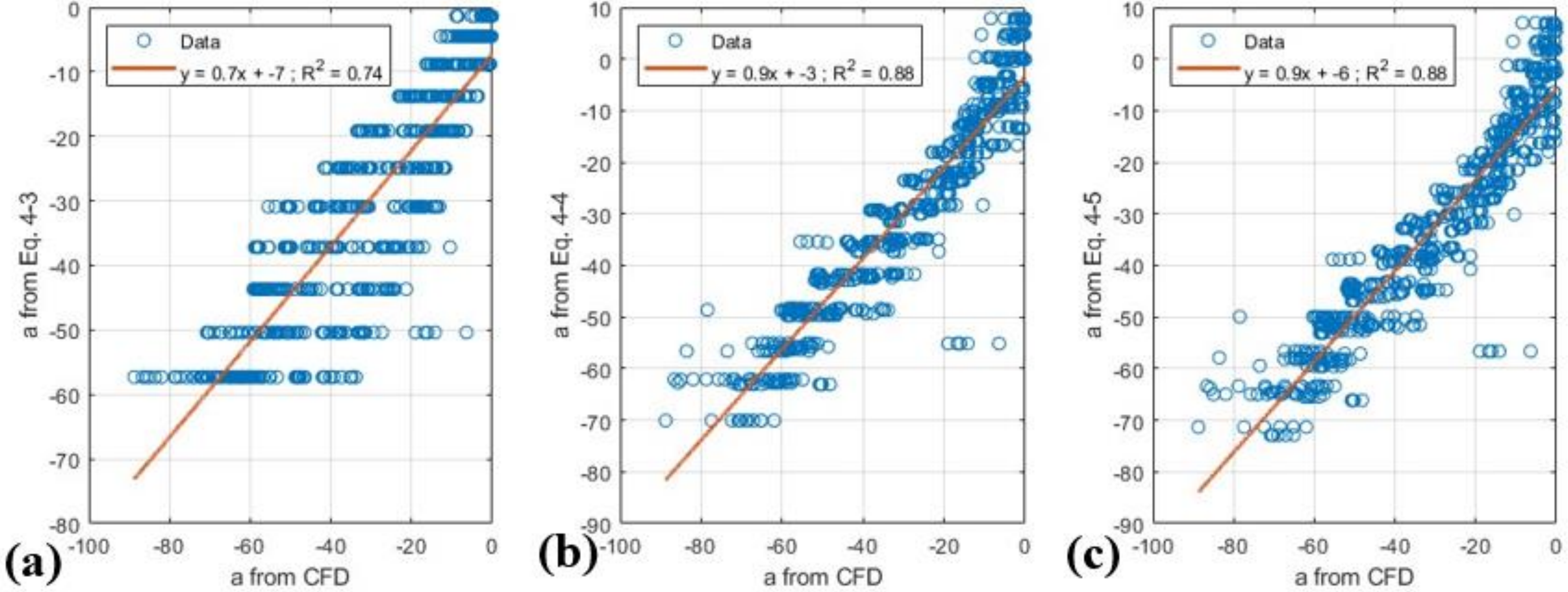
α = geotech absorption coefficient

Predicting Attenuation Without Measuring Sound at 1 Location

$a = a_1 + a_2\alpha$

$a = a_1 + a_2\alpha + a_3z + a_4w$

$a = a_1 + a_2\alpha + a_3z + a_4w + a_5A$

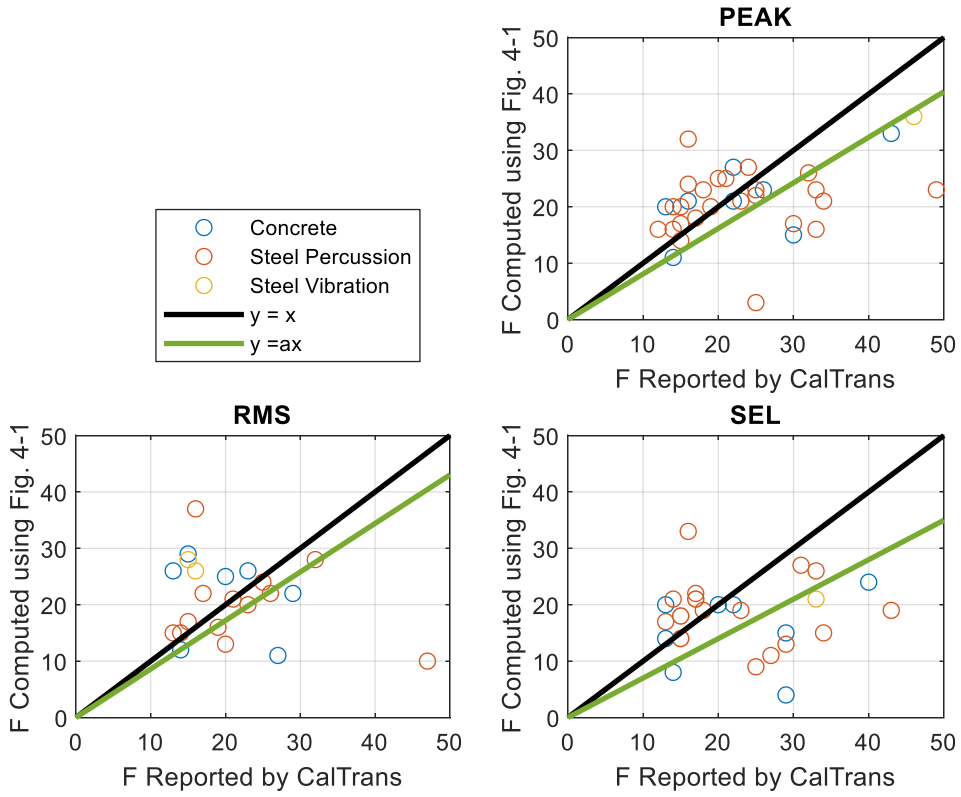


Modeled attenuation data based upon site conditions only using hypothetical CFD data

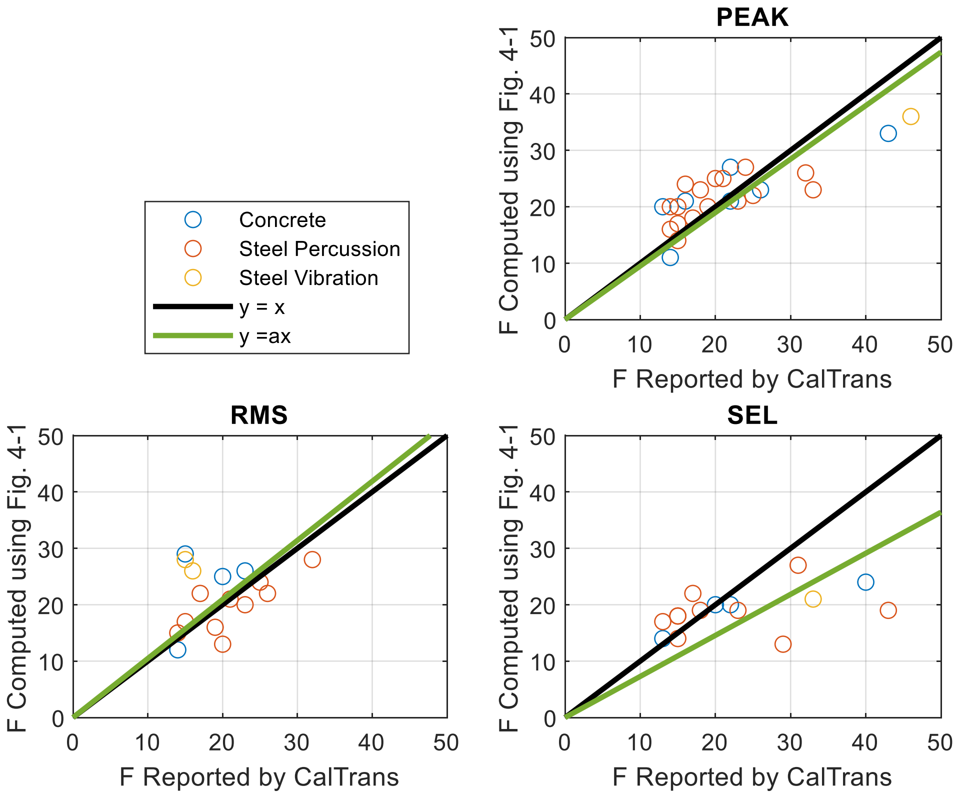
Verification

- Using 32 datasets from CalTrans, the FACT was verified
- Very few CalTrans data from concrete and vibratory piles; mostly from steel impact driving

Verification Results



Verification results using all data from CalTrans



Verification results using piles that conformed to FDOT piles

Task 4 – Stakeholder Meetings

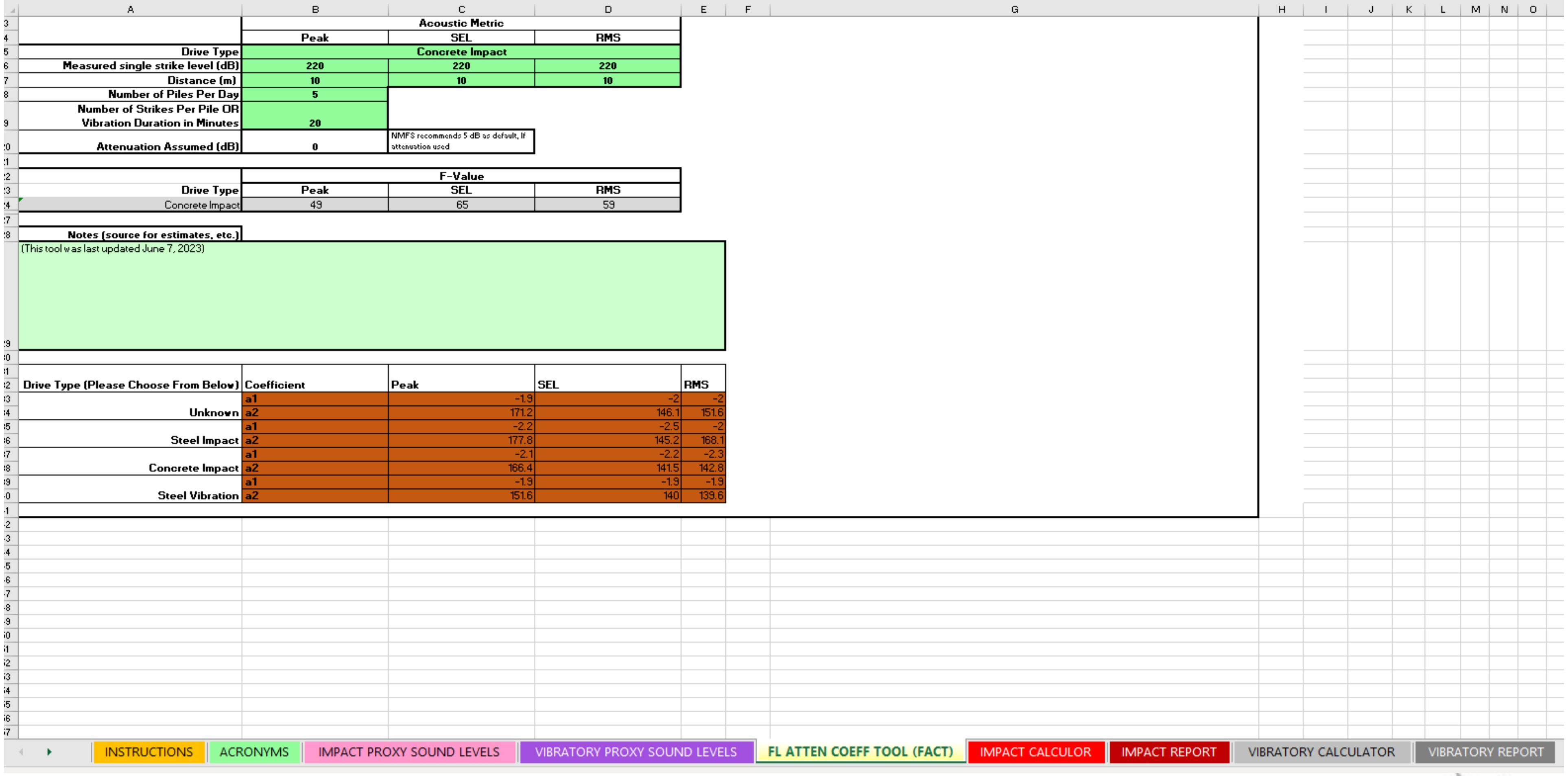
- Several meetings were held with stakeholders including representatives from NMFS, USFWS, and NOAA. These meetings began ~spring of 2021 and continued throughout the end of the project.

- As a result of these meeting, data analysis had to be repeated and reformatted several times to meet the agencies' expectations.

Task 5 – Technical Guidance

- The FACT was implemented in the NOAA/NMFS calculator

FACT/NMFS Calculator



	Acoustic Metric		
	Peak	**SEL**	**RMS**
Drive Type	**Concrete Impact**		
Measured single strike level (dB)	**220**	**220**	**220**
Distance (m)	**10**	**10**	**10**
Number of Piles Per Day	**5**		
Number of Strikes Per Pile OR Vibration Duration in Minutes	**20**		
Attenuation Assumed (dB)	**0**	NMFS recommends 5 dB as default, If attenuation used	

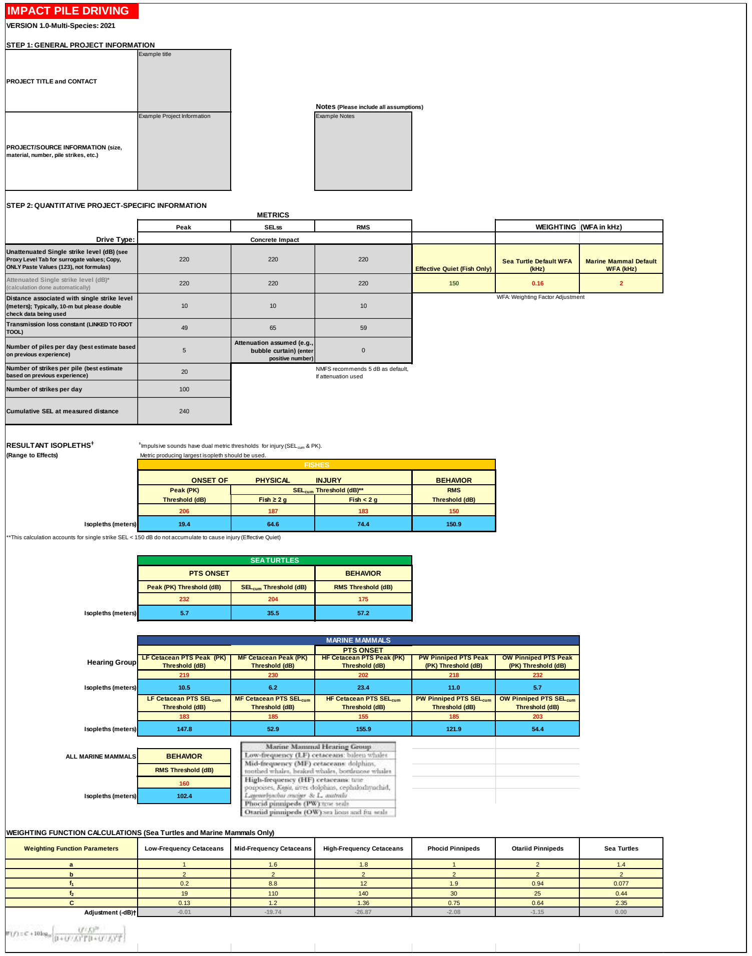
	F-Value		
Drive Type	**Peak**	**SEL**	**RMS**
Concrete Impact	49	65	59

Notes (source for estimates, etc.)

(This tool was last updated June 7, 2023)

Drive Type (Please Choose From Below)	**Coefficient**	**Peak**	**SEL**	**RMS**
Unknown	**a1**	-1.9	-2	-2
	a2	171.2	146.1	151.6
Steel Impact	**a1**	-2.2	-2.5	-2
	a2	177.8	145.2	168.1
Concrete Impact	**a1**	-2.1	-2.2	-2.3
	a2	166.4	141.5	142.8
Steel Vibration	**a1**	-1.9	-1.9	-1.9
	a2	151.6	140	139.6

FACT/NMFS Calculator



IMPACT PILE DRIVING

VERSION 1.0-Multi-Species: 2021

STEP 1: GENERAL PROJECT INFORMATION

PROJECT TITLE and CONTACT	Example title
PROJECT/SOURCE INFORMATION (size, material, number, pile strikes, etc.)	Example Project Information

Notes (Please include all assumptions)

Example Notes

STEP 2: QUANTITATIVE PROJECT-SPECIFIC INFORMATION

	METRICS				WEIGHTING (WFA in kHz)	
	Peak	SELss	RMS			
Drive Type:	Concrete Impact					
Unattenuated Single strike level (dB) (see Proxy Level Tab for surrogate values; Copy, ONLY Paste Values (123), not formulas)	220	220	220	**Effective Quiet (Fish Only)**	**Sea Turtle Default WFA (kHz)**	**Marine Mammal Default WFA (kHz)**
Attenuated Single strike level (dB)* (calculation done automatically)	220	220	220	150	0.16	2
Distance associated with single strike level (meters); Typically, 10-m but please double check data being used	10	10	10		WFA: Weighting Factor Adjustment	
Transmission loss constant (LINKED TO FDOT TOOL)	49	65	59			
Number of piles per day (best estimate based on previous experience)	5	**Attenuation assumed (e.g., bubble curtain)** (enter positive number)	0			
Number of strikes per pile (best estimate based on previous experience)	20		NMFS recommends 5 dB as default, If attenuation used			
Number of strikes per day	100					
Cumulative SEL at measured distance	240					

RESULTANT ISOPLETHS‡

(Range to Effects)

‡Impulsive sounds have dual metric thresholds for injury (SEL_{cum} & PK).
Metric producing largest isopleth should be used.

	FISHES			
	ONSET OF PHYSICAL INJURY			BEHAVIOR
	Peak (PK) Threshold (dB)	SEL_{cum} Threshold (dB)**		RMS Threshold (dB)
		Fish ≥ 2 g	Fish < 2 g	
	206	187	183	150
Isopleths (meters)	19.4	64.6	74.4	150.9

**This calculation accounts for single strike SEL < 150 dB do not accumulate to cause injury (Effective Quiet)

	SEA TURTLES		
	PTS ONSET		BEHAVIOR
	Peak (PK) Threshold (dB)	SEL_{cum} Threshold (dB)	RMS Threshold (dB)
	232	204	175
Isopleths (meters)	5.7	35.5	57.2

	MARINE MAMMALS				
			PTS ONSET		
Hearing Group	LF Cetacean PTS Peak (PK) Threshold (dB)	MF Cetacean Peak (PK) Threshold (dB)	HF Cetacean PTS Peak (PK) Threshold (dB)	PW Pinniped PTS Peak (PK) Threshold (dB)	OW Pinniped PTS Peak (PK) Threshold (dB)
	219	230	202	218	232
Isopleths (meters)	10.5	6.2	23.4	11.0	5.7
	LF Cetacean PTS SEL_{cum} Threshold (dB)	MF Cetacean PTS SEL_{cum} Threshold (dB)	HF Cetacean PTS SEL_{cum} Threshold (dB)	PW Pinniped PTS SEL_{cum} Threshold (dB)	OW Pinniped PTS SEL_{cum} Threshold (dB)
	183	185	155	185	203
Isopleths (meters)	147.8	52.9	155.9	121.9	54.4

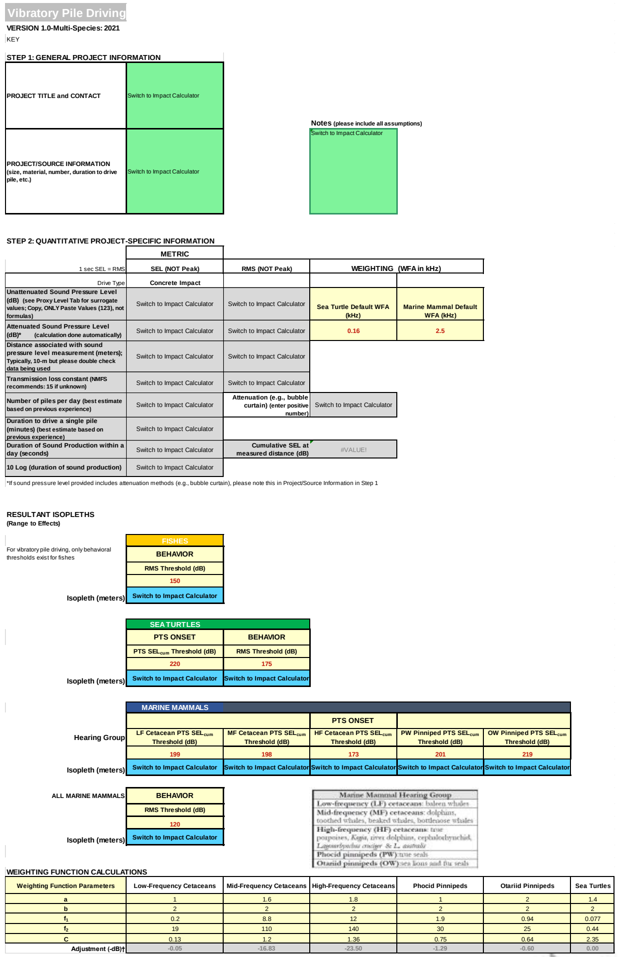
ALL MARINE MAMMALS	BEHAVIOR
	RMS Threshold (dB)
	160
Isopleths (meters)	102.4

Marine Mammal Hearing Group
Low-frequency (LF) cetaceans: baleen whales
Mid-frequency (MF) cetaceans: dolphins, toothed whales, beaked whales, bottlenose whales
High-frequency (HF) cetaceans: true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* & *L. australis*
Phocid pinnipeds (PW): true seals
Otariid pinnipeds (OW): sea lions and fur seals

WEIGHTING FUNCTION CALCULATIONS (Sea Turtles and Marine Mammals Only)

Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds	Sea Turtles
a	1	1.6	1.8	1	2	1.4
b	2	2	2	2	2	2
f_1	0.2	8.8	12	1.9	0.94	0.077
f_2	19	110	140	30	25	0.44
C	0.13	1.2	1.36	0.75	0.64	2.35
Adjustment (-dB)†	-0.01	-19.74	-26.87	-2.08	-1.15	0.00

$$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\}$$



Vibratory Pile Driving

VERSION 1.0-Multi-Species: 2021

KEY

STEP 1: GENERAL PROJECT INFORMATION

PROJECT TITLE and CONTACT	Switch to Impact Calculator
PROJECT/SOURCE INFORMATION (size, material, number, duration to drive pile, etc.)	Switch to Impact Calculator

Notes (please include all assumptions)

Switch to Impact Calculator

STEP 2: QUANTITATIVE PROJECT-SPECIFIC INFORMATION

	METRIC		WEIGHTING (WFA in kHz)	
1 sec SEL = RMS	SEL (NOT Peak)	RMS (NOT Peak)		
Drive Type	Concrete Impact			
Unattenuated Sound Pressure Level (dB) (see Proxy Level Tab for surrogate values; Copy, ONLY Paste Values (123), not formulas)	Switch to Impact Calculator	Switch to Impact Calculator	**Sea Turtle Default WFA (kHz)**	**Marine Mammal Default WFA (kHz)**
Attenuated Sound Pressure Level (dB)* (calculation done automatically)	Switch to Impact Calculator	Switch to Impact Calculator	0.16	2.5
Distance associated with sound pressure level measurement (meters); Typically, 10-m but please double check data being used	Switch to Impact Calculator	Switch to Impact Calculator		
Transmission loss constant (NMFS recommends: 15 if unknown)	Switch to Impact Calculator	Switch to Impact Calculator		
Number of piles per day (best estimate based on previous experience)	Switch to Impact Calculator	**Attenuation (e.g., bubble curtain)** (enter positive number)	Switch to Impact Calculator	
Duration to drive a single pile (minutes) (best estimate based on previous experience)	Switch to Impact Calculator			
Duration of Sound Production within a day (seconds)	Switch to Impact Calculator	**Cumulative SEL at measured distance (dB)**	#VALUE!	
10 Log (duration of sound production)	Switch to Impact Calculator			

*If sound pressure level provided includes attenuation methods (e.g., bubble curtain), please note this in Project/Source Information in Step 1

RESULTANT ISOPLETHS

(Range to Effects)

For vibratory pile driving, only behavioral thresholds exist for fishes

	FISHES
	BEHAVIOR
	RMS Threshold (dB)
	150
Isopleth (meters)	Switch to Impact Calculator

	SEA TURTLES	
	PTS ONSET	BEHAVIOR
	PTS SEL_{cum} Threshold (dB)	RMS Threshold (dB)
	220	175
Isopleth (meters)	Switch to Impact Calculator	Switch to Impact Calculator

	MARINE MAMMALS				
			PTS ONSET		
Hearing Group	LF Cetacean PTS SEL_{cum} Threshold (dB)	MF Cetacean PTS SEL_{cum} Threshold (dB)	HF Cetacean PTS SEL_{cum} Threshold (dB)	PW Pinniped PTS SEL_{cum} Threshold (dB)	OW Pinniped PTS SEL_{cum} Threshold (dB)
	199	198	173	201	219
Isopleth (meters)	Switch to Impact Calculator	Switch to Impact Calculator	Switch to Impact Calculator	Switch to Impact Calculator	Switch to Impact Calculator

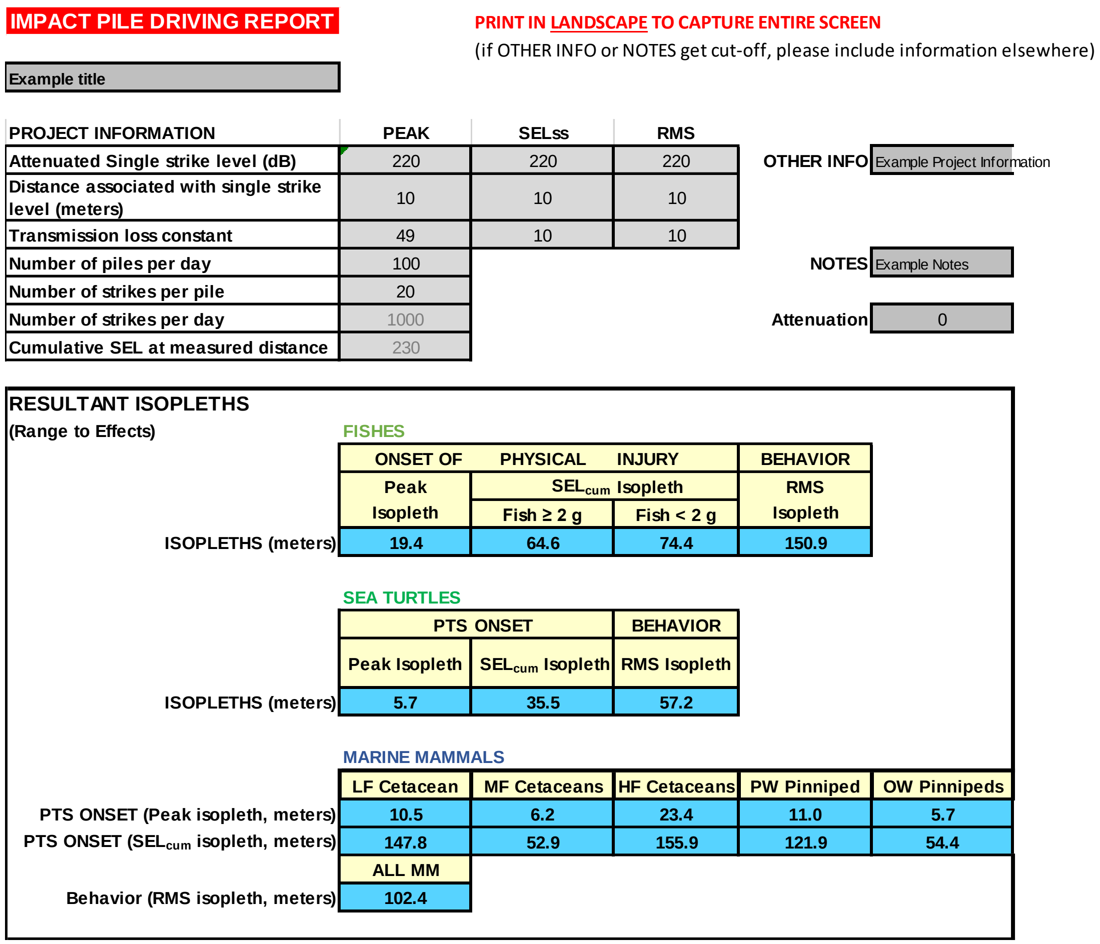
ALL MARINE MAMMALS	BEHAVIOR
	RMS Threshold (dB)
	120
Isopleth (meters)	Switch to Impact Calculator

Marine Mammal Hearing Group
Low-frequency (LF) cetaceans: baleen whales
Mid-frequency (MF) cetaceans: dolphins, toothed whales, beaked whales, bottlenose whales
High-frequency (HF) cetaceans: true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* & *L. australis*
Phocid pinnipeds (PW): true seals
Otariid pinnipeds (OW): sea lions and fur seals

WEIGHTING FUNCTION CALCULATIONS

Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds	Sea Turtles
a	1	1.6	1.8	1	2	1.4
b	2	2	2	2	2	2
f_1	0.2	8.8	12	1.9	0.94	0.077
f_2	19	110	140	30	25	0.44
C	0.13	1.2	1.36	0.75	0.64	2.35
Adjustment (-dB)†	-0.05	-16.83	-23.50	-1.29	-0.60	0.00

FACT/NMFS Calculator



IMPACT PILE DRIVING REPORT

PRINT IN LANDSCAPE TO CAPTURE ENTIRE SCREEN
(if OTHER INFO or NOTES get cut-off, please include information elsewhere)

Example title

PROJECT INFORMATION	PEAK	SELss	RMS
Attenuated Single strike level (dB)	220	220	220
Distance associated with single strike level (meters)	10	10	10
Transmission loss constant	49	10	10
Number of piles per day	100		
Number of strikes per pile	20		
Number of strikes per day	1000		
Cumulative SEL at measured distance	230		

OTHER INFO: Example Project Information

NOTES: Example Notes

Attenuation: 0

RESULTANT ISOPLETHS
(Range to Effects)

FISHES

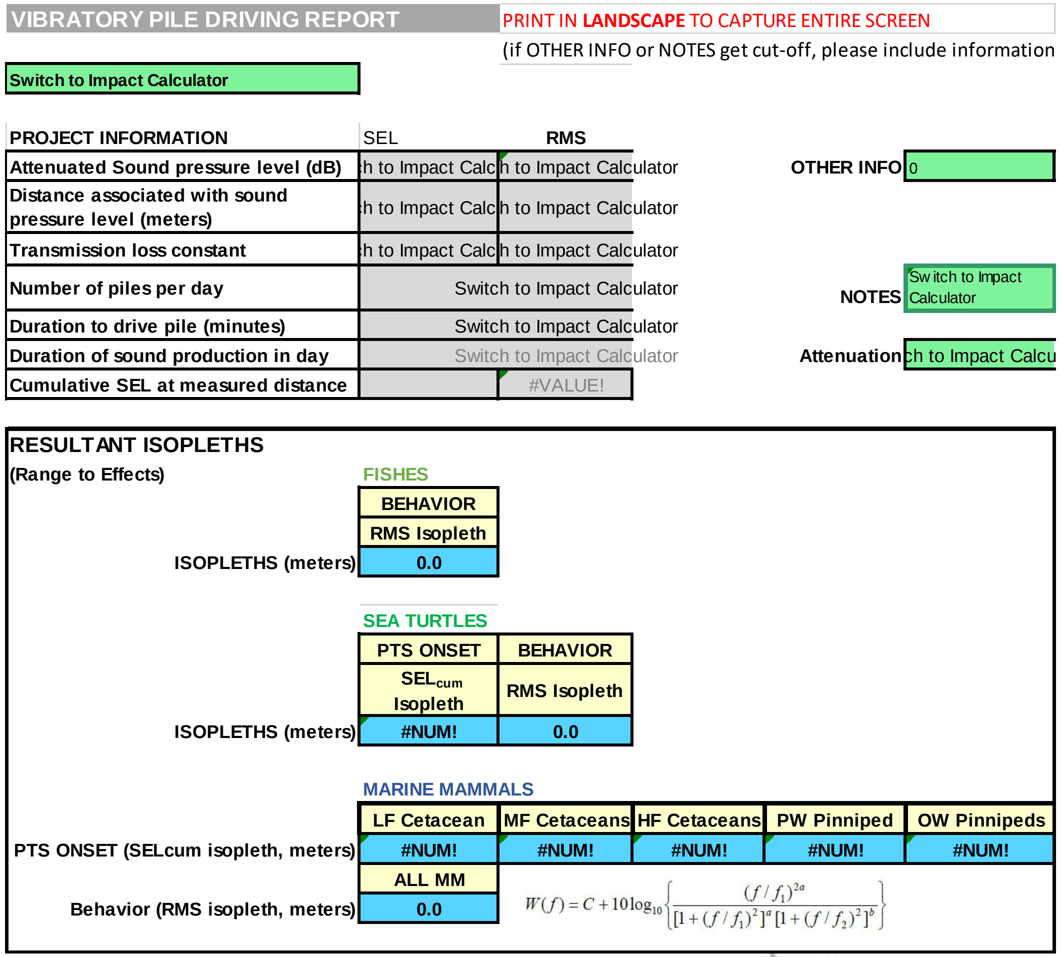
	ONSET OF	PHYSICAL INJURY		BEHAVIOR
	Peak Isopleth	SEL_{cum} Isopleth		RMS Isopleth
		Fish ≥ 2 g	Fish < 2 g	
ISOPLETHS (meters)	19.4	64.6	74.4	150.9

SEA TURTLES

	PTS ONSET		BEHAVIOR
	Peak Isopleth	SEL_{cum} Isopleth	RMS Isopleth
ISOPLETHS (meters)	5.7	35.5	57.2

MARINE MAMMALS

	LF Cetacean	MF Cetaceans	HF Cetaceans	PW Pinniped	OW Pinnipeds
PTS ONSET (Peak isopleth, meters)	10.5	6.2	23.4	11.0	5.7
PTS ONSET (SEL_{cum} isopleth, meters)	147.8	52.9	155.9	121.9	54.4
	ALL MM				
Behavior (RMS isopleth, meters)	102.4				



VIBRATORY PILE DRIVING REPORT

PRINT IN LANDSCAPE TO CAPTURE ENTIRE SCREEN
(if OTHER INFO or NOTES get cut-off, please include information

Switch to Impact Calculator

PROJECT INFORMATION	SEL	RMS
Attenuated Sound pressure level (dB)	:h to Impact Calc	h to Impact Calculator
Distance associated with sound pressure level (meters)	:h to Impact Calc	h to Impact Calculator
Transmission loss constant	:h to Impact Calc	h to Impact Calculator
Number of piles per day	Switch to Impact Calculator	
Duration to drive pile (minutes)	Switch to Impact Calculator	
Duration of sound production in day	Switch to Impact Calculator	
Cumulative SEL at measured distance		#VALUE!

OTHER INFO: 0

NOTES: Switch to Impact Calculator

Attenuation: ch to Impact Calcu

RESULTANT ISOPLETHS
(Range to Effects)

FISHES

	BEHAVIOR
	RMS Isopleth
ISOPLETHS (meters)	0.0

SEA TURTLES

	PTS ONSET	BEHAVIOR
	SEL_{cum} Isopleth	RMS Isopleth
ISOPLETHS (meters)	#NUM!	0.0

MARINE MAMMALS

	LF Cetacean	MF Cetaceans	HF Cetaceans	PW Pinniped	OW Pinnipeds
PTS ONSET (SELcum isopleth, meters)	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
	ALL MM				
Behavior (RMS isopleth, meters)	0.0				

$$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\}$$

Summary, Research Conclusions, and Recommendations

- Underwater noise data were collected at 13 sites around Florida. Overall, data from 98 drive events were collected. Data were collected from five sites in northeast Florida, two sites from the Panhandle; three sites near Tampa Bay; one site near Cape Canaveral; and one site near Port St. Lucie.
- Computational analysis using CFD showed that geometrical spreading coupled with local bathymetry data could not explain measured field data. However, inclusion of bottom absorption allowed one to accurately reproduce field data.
- Analysis of these data showed that usually, using an F-value of 15 to predict underwater TL may be overly conservative for concrete piles in the sense that this estimate for F may underpredict sound attenuation. For steel piles driven via a percussion hammer, using an F-value of 15 was relatively close to measured data most of the time. While data from steel vibrational drives showed much higher attenuation than $F = 15$, and verification produced relatively accurate results, these data are limited and should be treated cautiously.
- Field data showed that sound attenuation was frequency dependent in the sense that very low frequencies (i.e., less than ~100 Hz to ~1,000 Hz) tended to attenuate faster than relatively high frequency sound.
- Mathematical analysis showed that the frequency dependency in attenuation was interrelated to the attenuation associated with geometrical spreading (i.e., the F-values or a terms presented throughout this report).

Summary, Research Conclusions, and Recommendations

- Based upon the field data, a new design tool was developed to estimate *F*-values that was dubbed the FACT. The FACT is based upon the interplay between attenuation and the source-level that were consistently apparent in both field and hypothetical computational data. Its limitations are (i) it requires sound-level to be known at some distance from a pile drive; and (ii) the sound-level used in (i) must be above some threshold associated with the design tool's coefficient. In addition, we recommend using this tool only for piles of similar shape and dimension as the piles studied and verified in this report. Specifically, these are:

    i) Square concrete piles between 18 inches and 36 inches wide driven via impact driving.

    ii) Circular steel piles or sheet piles driven with an impact hammer up to a maximum diameter of 66 inches.

    iii) 18-inch wide sheet piles driven with a vibrational hammer or 24-inch diameter circular piles driven with a vibrational hammer.

    iv) Water depths between 2 m and 15 m.

- The FACT was verified using data reported by CalTrans (Buehler et al. 2015) at 32 sites where *F*-values were reported explicitly and where reported sound-levels were above the threshold mentioned above. In general, the FACT performed well in the sense that most of the time, it returned *F*-value that were either within 5 dB of reported values or were conservative.

Project Benefits

- Quantitative
  - New quantitative design tool designed for <u>Florida-specific</u> pile driving using data from Florida

- Qualitative
  - Prior to this project, all underwater noise due to pile driving relied upon data from CalTrans

Implementation Items

- The FACT is easy to implement, and a MS Excel spreadsheet/calculator has already been developed for this

Publications

- Crowley, R., Makoleo, M.*, Mushi, C.*, Schaaf, A.*, Sapp, E.*, Gelsleichter, J., and Shamet, R. (abstract accepted, 2024). Validation of an empirical model for underwater noise due to pile driving based upon high attenuation at lower frequencies in shallow water. *GeoenvironMeet 2024*, Portland, OR, Sep. 28-11.
- Crowley, R., Schaaf, A.*, Mushi, C.*, Makoleo, M.*, Sapp, E.*, Gelsleichter, J., and Kopp, B.T. (abstract accepted, 2024). Refinement and implementation of a new empirical model for predicting underwater noise due to pile driving. *Geo-Congress 2024*, Vancouver, BC, Feb. 25-28.
- Crowley, R., Schaaf, A.*, Mushi, C.*, Makoleo, M.*, Kopp, B., Dally, W.R., and Gelsleichter, J. (2023). Development of a new empirical model for predicting underwater noise due to pile driving. *Geo-Congress 2023*, Los Angeles, CA, March 26-29.
- Bosco, M.*, Crowley, R., Sypula, D.*, Schaaf, A.*, Rivera, B.*, Kopp, B., Dally, W.R., and Gelsleichter, J. (2022). Analysis of anthropogenic noise due to pile driving using computational fluid dynamics. *Geo-Congress 2022*, Charlotte, NC, March 20-23.
- Crowley, R., Berube, J.*, Matemu, C.*, Clark, M.*, Kopp, B., Dally, W.R., and Gelsleichter, J. (2020). Development of a unique instrumentation system to monitor underwater noise due to pile driving. *Geo-Congress 2020*, Minneapolis, MN, February 25.

UNF UNIVERSITY of NORTH FLORIDA

Equipment

- Hydrophones/buoys – still at UNF but can be used in the future if needed

Thank you for Supporting this Research!