Underwater Noise Monitoring Report

SR 520 Evergreen Point Floating Bridge and Landings Project

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List of Abbreviations/Acronyms

Abbreviation/ Acronym	Definition
CDF	Cumulative Distribution Function
dB	Decibel
ECP	Environmental Compliance Plan
ESA	Endangered Species Act
Hz	Hertz
KGM	Kiewit/General/Manson, A Joint Venture
kHz	Kilohertz
kPa	kiloPascal
μPa	microPascal
NIST	National Institute of Standards and Technology
NMFS	National Marine Fisheries Service
OHW	Ordinary High Water
PDF	Probability Density Function
RFP	Request for Proposal
RMS	Root Mean Square
SEL	Sound Exposure Level
Services	USFWS and NMFS
SPL	Sound Pressure Level
SR 520 FBL Project	State Route 520 Evergreen Point Floating Bridge and Landings Project
UNMP	Underwater Noise Monitoring Plan
USFWS	U.S. Fish and Wildlife Service
WSDOT	Washington State Department of Transportation

Executive Summary

This report is submitted to satisfy the Underwater Noise Monitoring Plan, Appendix J of the Environmental Compliance Plan for the State Route 520 Evergreen Point Floating Bridge and Landings Project (SR 520 FBL Project).

As stated in the UNMP and as modified by the Services (USFS and NMFS), the results of hydroacoustic monitoring of 6 piles was conducted. Hydroacoustic monitoring of the 6 steel piles indicated that single-strike sound levels did not exceed the take limits set forth in Biological Opinions (NMFS 2011, USFWS 2011). Cumulative SEL exceeded the 187dB threshold for 5 of 6 piles driven. See Results Section 7.0.

1.0 Introduction

The Underwater Noise Monitoring Results (UNMR) for the State Route 520 Evergreen Point Floating Bridge and Landings Project (SR 520 FBL Project) was prepared in accordance to Appendix J of the Underwater Noise Monitoring Plan (UNMP) as presented in the Environmental Compliance Plan (ECP) required by the Projects Environmental Commitments List (Request For Proposal [RFP] Appendix C1; WSDOT 2010) and the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS; together, the Services) Biological Opinions terms and conditions for the State Route 520 Evergreen Point Floating Bridge and Landings Project (SR 520 FBL Project). The purpose of the UNMR is to present the results of in-water pile driving monitoring and it's effect on Endangered Species Act (ESA) listed fish and their prey during construction of the SR 520 FBL Project.

1.1 Project Description and Site Location

The SR 520 FBL Project site includes both upland areas within Medina and over-water areas within Lake Washington in both City of Medina and City of Seattle jurisdictions. In-water pile driving for the SR 520 FBL Project was monitored at the following location:

Temporary East Approach Work Trestle and Ramp: To construct the east approach of the new bridge, a temporary work trestle was needed. The temporary work trestle was built on twenty-three 24–inch-diameter steel piles. In addition, thirteen 24-inch-diameter piles were placed off of the end of the trestle to support a moveable unloading ramp and an alignment dolphin (Figure 1). Of the piles described above for the work trestle, ramp, and dolphin, one pile of each piling bent was also be battered.

A total of 6 piles were monitored at the start of construction of the temporary work trestle. Refer to Figure 1 for pile locations.

2.0 Purpose

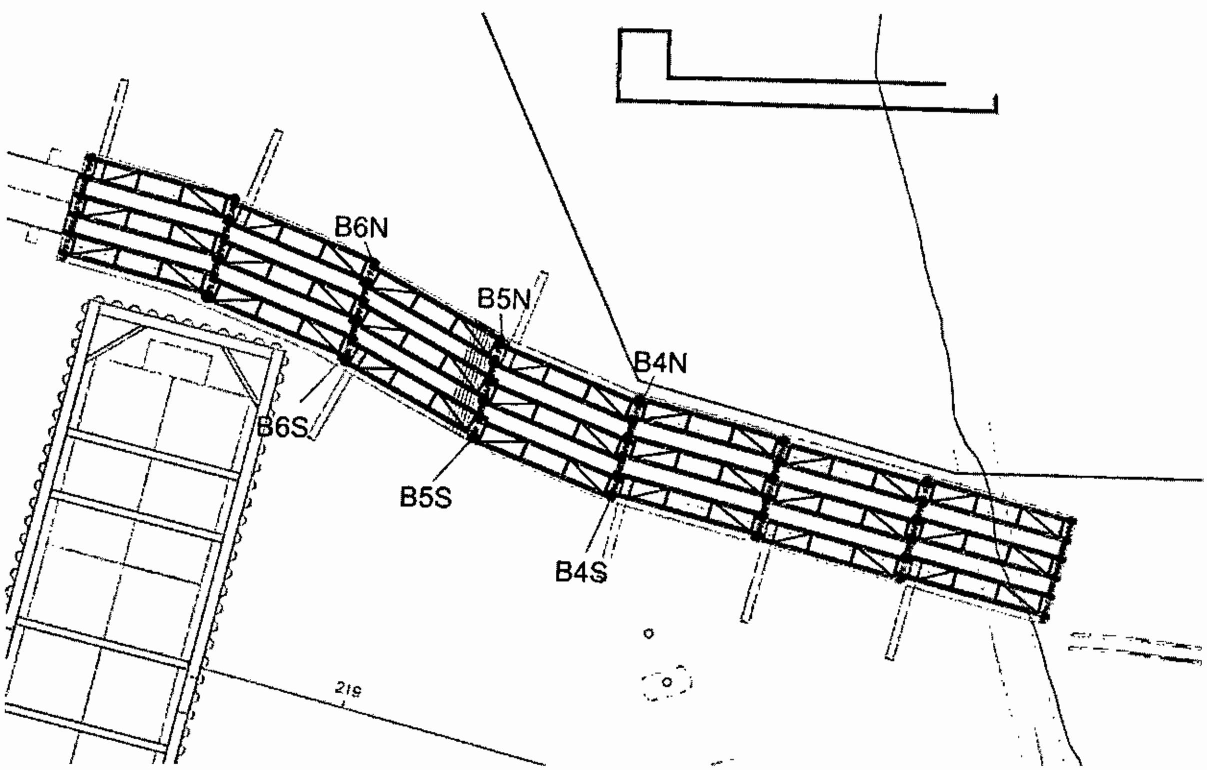
The purpose of underwater noise monitoring is to monitor the number of pile strikes and associated underwater noise levels at a representative number of steel piles to comply with the NMFS and USFWS Biological Opinions' exempted take limits. The monitoring was performed to evaluate underwater noise levels and ambient (background) conditions during the impact pile driving of steel piles in the eastside staging area and east approach work trestle.

This document defines the following:

- Location of steel piles that were monitored
- Monitoring methodology and equipment used
- Methodology of signal processing
- Data analysis methodology
- Results

3.0 Pile Installation Monitoring Locations

Figure 1: Locations of Monitored Piles



4.0 Monitoring Methodology

Installation of six 24-inch diameter steel piles was monitored with a hydrophone to determine the underwater noise levels associated with the driving of each pile. The hydrophone was located 10 meters waterward from each pile with a clear line of sight between the pile and hydrophone. The distance between each pile and hydrophone was measured by tape measure attached to a magnet. The magnet was placed on the pile to be monitored, and once the hydrophone was 10m from the pile the boat was anchored the tape was pulled off the pile. The direct measurement was supplemented with a Leupold laser range finder to verify that distance was maintained during the individual driving activities.

Once the 10 meter distance was established, each hydrophone was located at mid-water depth (see Appendix 5). Each hydrophone was attached to a nylon cord with an anchor at the bottom and a float or static line at the surface to keep the hydrophone in place.

Bubble curtains were employed during impact pile driving to provide sound attenuation. The bubble curtains met the design requirements from Appendix E6-05 of the project RFP. Both two ring and five ring bubble curtains were used, with the two ring curtain being used in water up to 14 feet deep, and the five ring version being used in deeper water. The air compressor output volumes feeding the rings were determined by Columbia-Sentinel Engineers, Inc. (see Appendix 7, p. 38). During installation of piles 1 and 2, each pile was tested with the sound attenuation system on and off (presence and absence) to test its effectiveness. To account for varying resistance as the pile was driven; the sound attenuation device was turned off for 30-second periods during the beginning, the middle third, and near the end of the drive.

Pile driving resumed for a minimum of two minutes after each 30-second period that the attenuation device was off. For piles that required less than 5 minutes to drive, the sound attenuation system was turned off for only two 30-second periods, one near the beginning and once near the end of the drive. Up to 500 unattenuated strikes per day are allowed to establish the baseline sound levels. This monitoring was performed in order to establish the effectiveness of the attenuation device.

KGM informed the acoustics monitoring subcontractor when pile driving was about to start to ensure that the monitoring equipment was in place and operational. Underwater sound levels were continuously monitored during the entire duration of installation of each of the 6 previously identified piles being driven. Peak levels of each strike were monitored (in dB) in real time.

Background ambient sound levels were monitored in the same location using a high sensitivity hydrophone and preamplifier. Had the same hydrophone that was employed for the pile driving monitoring been used, the system noise floor would have been at least 40dB above actual ambient levels. See Table 1 for equipment used.

4.1 Equipment and Calibration

Table 1 details the equipment that was utilized to monitor the underwater sound pressure levels (SPLs).

Table 1: Equipment Summary

Item	Specifications	Quantity	Usage
Model CR3 hydrophone with 15 meter cable, S/N 9196-07. NRL Traceable calibration performed at NUWC – Keyport	Receiving sensitivity: 209 dB ± 3 dB re 1V/µPa	1	Capture underwater sound pressures and convert to voltages that can be recorded/analyzed by MDR/SLM
NIST certified Model PC200, Dual Channel,	Amplifier Gain Steps: 1x, 10x, 100x	1	Increase effective system sensitivity to allow

voltage preamplifier			recording of low level ambient sounds
SpectraLab signal analysis software	Time series and spectral analysis features. >1Mhz sample rate ANSI S1.11 and IEC1260 compliant	1	Analysis of absolute sound pressure levels
NIST certified Model ST1400ENV Mobile Data Recorder and Sound Level Monitor	Dual Channel: 50 kHz sample rate	1	Record, analyze, and log acoustic data
Model C55 hydrophone with 27 m cable, S/N 423. NRL traceable calibration performed at NUWC – Keyport	Receiving sensitivity: 165$\pm$ 3 dB, re 1V/μPa	1	Convert quiet ambient sounds to voltage for recording and analysis

Refer to Appendix 5 for pile driving equipment specifics, substrate, and depths piles were driven.

4.2 Documentation on Underwater Noise Monitoring Data

Prior to and during the pile driving activity, environmental data were gathered to provide relative background information. Data collected included wind speed and direction, air temperature, humidity, surface water temperature, water depth, wave height, weather conditions, and other factors that could influence the underwater sound levels (e.g., aircraft, boats, etc.). Start and stop times for each pile driving event was recorded.

5.0 Signal Processing

Analysis of sound level signals included determining the maximum absolute value of the instantaneous pressure from each strike, and then performing detailed analysis on the loudest strike from each pile. This analysis included determination of peak SPL, RMS-90% (RMS value calculated over 90% of the energy), and SEL for the strike. General analysis also included the number of strikes exceeding 206 dB_{peak}, (the NMFS Biological Opinion Peak SPL threshold), the cumulative sound exposure level (SEL) for each pile, and the percent of individual strikes occurring after the SEL exceeded 187dB (the NMFS Biological Opinion Cumulative SEL threshold for fish sizes of 2 grams or greater).

Background sound levels were analyzed by calculating 30-second RMS values. These values were plotted on a cumulative distribution function (CDF). The average background sound level was estimated using the 50 percent CDF (Appendix 3).

6.0 Data Analysis Methodology

The single-strike SEL associated with the highest peak strike (absolute value) was computed and plotted for those strikes. RMS values obtained for those strikes were computed for 90 percent of the energy of the sound pulse. A comparison of the frequency content with and without noise attenuation was conducted, and example spectra are plotted (Appendix 4).

Initially the assumption was made that each pile would take 100 to 200 strikes to drive. However, due to substrate variations, this was only true for pile 1. The subsequent 5 piles each took approximately 1000 strikes to drive. This resulted in a much larger data set. This report summarizes the most important information necessary for noise compliance. These are the individual loudest strike per pile, cumulative SEL per pile, and the cumulative distribution function of ambient sound levels.

It was assumed that signals from pile driving could reach peak pressures of 210 dB. Therefore, the Navy calibrated model CR3 hydrophone was deemed necessary in order to capture these higher signals. This resulted in the noise floor of the monitoring system being higher than desired for measuring lower level strike impulses. In addition, it appears that the data acquisition system started to experience increased self-noise near the end of the monitoring period. This made it increasingly difficult to distinguish low level strikes from the noise. However, low level strikes were analyzed using a logarithmic time series and spectrogram. Use of a spectrogram makes it much easier to detect low level signals. (Appendix 2)

Units of underwater SPL are dB, re: 1μPa. Units of SEL are dB, re: 1$\mu Pa^2 s$.

7.0 Results

Table 2 shows the information required for noise compliance per the NMFS Biological Opinion as it relates to peak SPL threshold (206 dBpeak).

None of the six piles monitored during impact driving exceeded the per-strike peak (SPL) at any time during the entire driving event. Due to the large number of strikes needed to drive 5 of the 6 piles, the cumulative SELs for those piles exceeded the 187dB threshold. The ST1400ENV used in this project, logs cumulative SEL but is not configured to display that data in real time, and requires post processing to determine those values.

Table 2: Pile Peak Pressures, RMS, and SEL

Pile #	Loudest Strike #	Loudest Peak Pressure [kPa]	Loudest Peak Pressure [dB]	Loudest RMS Pressure [dB]	Loudest SEL [dB]	Date	Strike Count
1	76	1.534	183.7	168.3	165.5	8/21/12	116
2	435	11.423	201.2	180.3	175.8	8/21/12	981
3	97	1.388	182.8	163.8	163.8	8/22/12	1179
4	248	0.909	179.2	160.8	160.4	8/22/12	1488
5	92	1.886	185.5	165.2	165.7	8/22/12	1631
6	134	3.026	189.6	168.5	169.1	8/22/12	1299

Table 3 shows the cumulative SEL for each pile and the percent strikes that occurred after that limit had been reached, as well as the distance to the 187 dB SEL threshold and 100.4dB background levels, and the area exposed to cSELs greater than 187dB. The programming in the ST1400ENV accumulates all sound received by the hydrophone, not just the individual strikes, making it a better measure of the actual sound exposure a fish in the same location as the hydrophone would be exposed to. That biases the data high by as much as 2-3 dB, but is a more conservative measure of the cumulative SEL. Alternative estimates of cumulative SEL that omit the sound exposure between strikes tend to bias the data low, making them a less conservative measure (by perhaps 2-3 dB) of the exposure a fish might have under the same circumstances. If the data were calculated using the less conservative methodology, and the cumulative SEL swing between the two formulae were at the maximum differential of 6 dB, Pile #4 in Table 3 would have been below the threshold limit of 187 dB, while the remaining four piling would still have exceed that limit, though the exceedence would have been smaller in magnitude.

Table 3: Distance from pile to BO limits

Pile #	Cumulative SEL [dB]	Strikes after 187 dB threshold reached [% Total]	Estimated Distance to 187dB assuming $15Log(R_2/R_1)$* spreading [m]	Estimated Distance to 100.4dB background level assuming $15Log(R_3/R_1)$* spreading [km]	Estimated Area Exposed to Cumulative SEL > 187dB assuming $15Log(R_2/R_1)$* spreading [acres]
1	180.73	0	4	2,266	0.0031
2	199.99	95	73	43,585	3.3
3	193.10	76	26	15,136	.072
4	192.58	73	24	13,974	1.18
5	195.58	89	37	22,148	0.66
6	198.96	93	63	37,211	2.66

* R1 = Distance from pile where measurement was taken
R2 = Distance from pile to 187dB Cumulative SEL Threshold
R3 = Distance from pile to 100.4dB ambient background level. No propagation modeling was been performed in this analysis to account for acoustic absorption or other factors.

Note: The ST1400ENV includes the sound levels between strikes when computing the SEL. This causes the end result to be slightly higher (by 2-3dB) than if only the SEL for individual strikes were accumulated.

Piles 1 - 3 were also analyzed to determine the minimum, maximum, and mean SPLs. Note: (Table 4)

Table 4: Min, Max, and Mean SPLs for piles 1, 2 & 3

	Pile 1		Pile 2		Pile 3	
	Peak	RMS	Peak	RMS	Peak	RMS
Mean SPL [kPa]	0.907	0.203	3.736	0.667	0.874	0.145
Standard Deviation [kPa]	0.264	0.029	1.181	0.142	0.247	0.028
Mean SPL [dB]	179.2	166.2	191.4	176.5	178.8	163.2
Min SPL [dB]	173.3	160.3	185	170.3	166.7	158.3
Max SPL [dB]	183.7	168.3	201.2	182.4	184.7	168.3

Refer to Appendix 1 for the following:

- Plots of cumulative SEL for all 6 piles that were driven. Includes overlays of peak and RMS SPL for the first two piles driven.
- Plots of SEL and absolute peak pressure for the loudest strike of each pile

Analysis of average spectra of strikes with and without noise attenuation showed that use of the bubble curtain reduced sound levels between 700Hz and 1kHz by approximately 6dB. In addition, sound levels between 1.1kHz and 1.8kHz were reduced by approximately 3dB, and levels between 4kHz and 10kHz were reduced by 1-2dB. (Appendix 4)

7.1 Ambient Noise Results

Ambient noise levels were monitored separately from the pile driving. 72 hours of background data was collected during 520 bridge closures on the weekends of September 22nd-23rd and November 17th-18th in the same vicinity of the monitored pile driving. While there was occasional ancillary boat traffic, care was taken not to record any data during heavy construction activities (vibratory driving of sheet piles in the area). Cumulative distribution functions and probability distribution functions (CDF and PDF) were developed from the data compiled. In addition, an ambient spectrogram plot was developed. Refer to Appendix 3 for Ambient Noise Results.

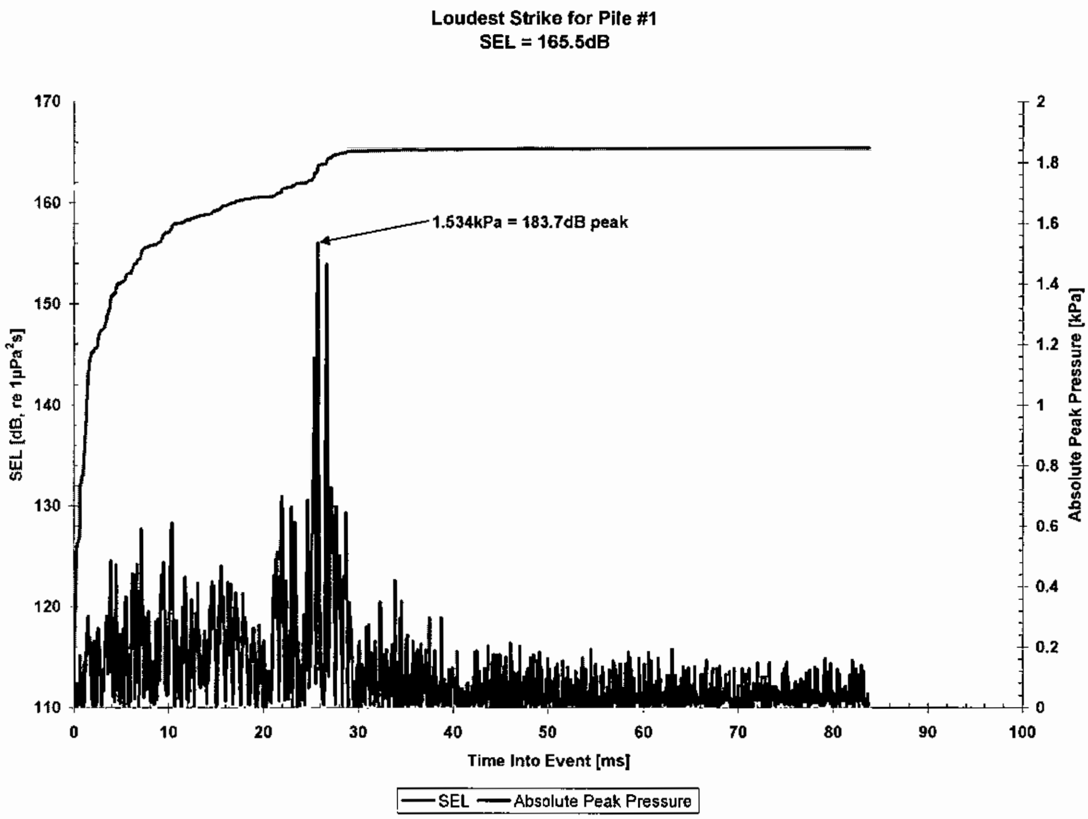
The 50^{th} percentile ambient SPL was determined to be 100.4 dB rms.

8.0 Conclusion

Six 24-inch diameter steel piles were monitored for peak SPLs, peak SELs, and cumulative SELs for the SR 520 FBLP in order to determine if take limits were exceeded as set forth in the Biological Opinion (NMFS, USFWS). Results of hydroacoustic analysis show that all six piles monitored at 10 meters were below the peak SPL injury threshold. The cumulative SEL threshold of 187dB was exceeded for 5 of the 6 piles, with distances from the pile to the resulting 187dB isopleth ranging from 24m to 73m.

Appendix 1: Loudest Strike SEL /Peak Pressure and Cumulative SEL Graphs for each pile (absolute value)

Figure 2: Pile 1 Graphs



Appendix 7: Bubble Curtain Compressor Sizing

COLUMBIA-SENTINEL ENGINEERS, INC.

Dellus Clark
K / G / M a Joint Venture
SR 520 Evergreen Point Floating Bridge
3015 112th Ave NE, Suite 100
Bellevue, WA. 98004

File: 1205
14 August 2012

Subject: Bubble Curtain compressor sizing for pile driving

Dear Mr. Clark,

Columbia-Sentinel Engineers, Inc. (CSE) has calculated the required compressor sizes for a two ring and a five ring bubble curtain system.

For the five ring curtain system CSE calculates 76 psi is required so the compressors should be provide their CFM at 84 psi to give a 10 % margin. CSE calculates the five ring system to require 3135 CFM which also includes a 10% margin.

For the two ring curtain system CSE calculates 66 psi is required so the compressors should be provide their CFM at 73 psi to give a 10 % margin. CSE calculates the two ring system to require 1254 CFM which also includes a 10% margin.

Call if you have more ring curtain systems you need the compressor sizing calculated for.

Very Truly Yours,

J. Paul Zankich, P.E.
Principal Naval Architect
Columbia-Sentinel Engineers, Inc

L. PAUL ZANKICH
STATE OF WASHINGTON
REGISTERED
PROFESSIONAL ENGINEER

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Appendix 8: Qualifications

NICHOLAS J. MARTIN

Nicholas Martin has over 15 years of experience working in marine technical data collection environments. As the founder of the DredgeTech, LLC., the last five years have been focused on hydroacoustic monitoring and high resolution multi-beam surveys. Mr. Martin is certified by HYPACK to train and implement it's software for survey, positioning, and water quality projects. Mr. Martin has worked on variety of scientific investigations in the Washington State and throughout the US.

Education
BS Mechanical Engineering, Arizona State University, 1996.

JOSEPH R. OLSON

Owner, Cetacean Research Technology, Seattle, Washington. (January 1994 to Present)
Mr. Olson specializes in the design, fabrication and sales of hydrophones and underwater acoustic systems, as well as noninvasive suction attachment systems for marine mammal research. He also specializes in the sales and support of signal analysis software and hardware, consultation in the areas of electronic instrumentation, underwater and bioacoustics signal analysis, and physics, and field research in cetacean acoustics.

Education
BS Physics, University of Washington, 1987.