SR 520 Montlake to Lake Washington I/C and Bridge Replacement
UNDERWATER NOISE MONITORING PLAN

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November 18, 2019

INTRODUCTION

Washington State Department of Transportation (WSDOT) construction is underway for the Montlake to Lake Washington I/C and Bridge Replacement stage of the SR 520 Bridge Replacement and HOV Program. A new West Approach Bridge South will be constructed parallel to the completed West Approach Bridge North, which will carry three lanes of eastbound traffic to the new floating bridge. The SR 520 / Montlake Boulevard East interchange will be rebuilt, and a highway lid and transit hub at Montlake Boulevard East will provide connection between the communities on either side of SR 520. The proposed project will require the installation of permanent and temporary piles in Lake Washington in Union Bay. See vicinity map (Figure 1).

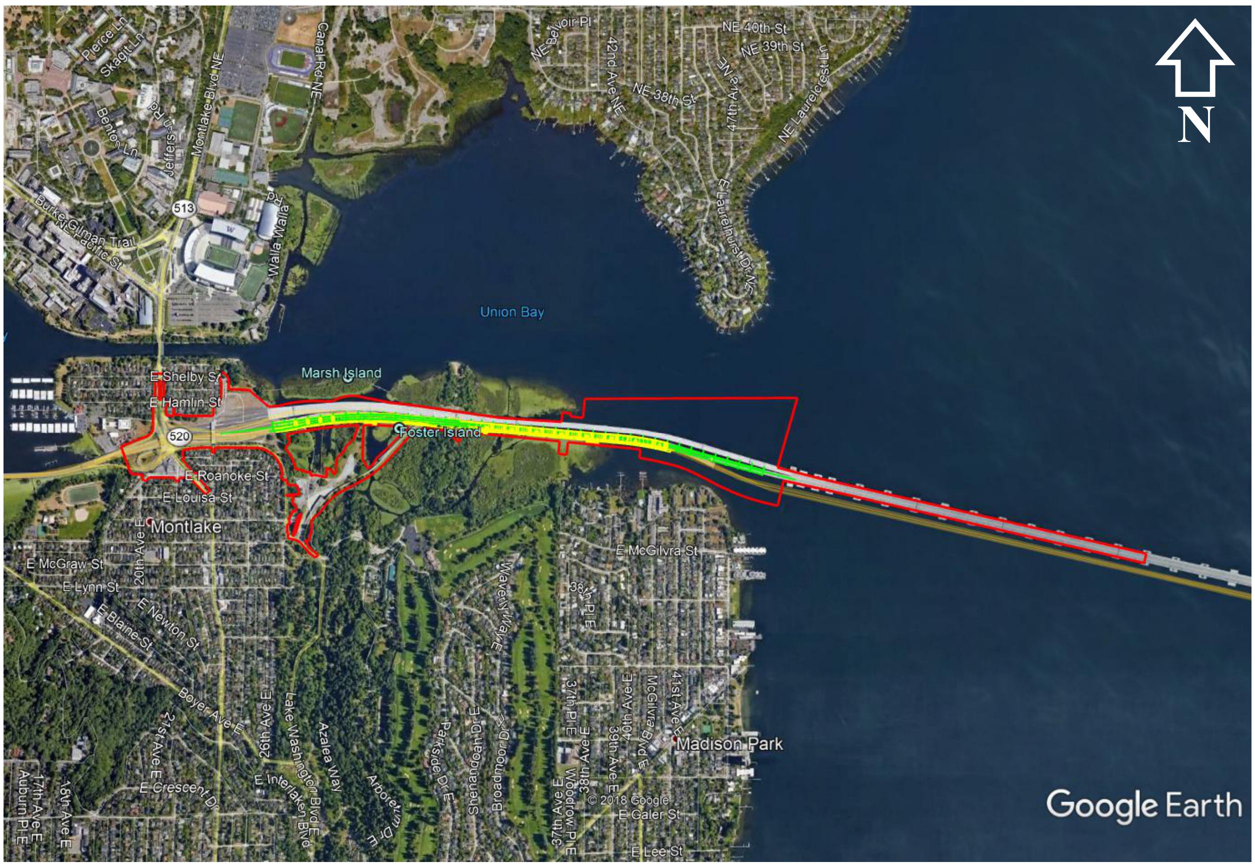

Figure 1. Vicinity map of SR 520 Bridge Replacement.

PROJECT AREA

The project will replace the Evergreen Point West Approach (WSDOT Bridge Number 520/7.5), Union Bay Bridge (WSDOT Bridge Number 520/6), and select portions of Evergreen Point West Approach Connection (WSDOT Bridge Number 520/7.7S) with a new West Approach Bridge South (WABS) structure. The replaced structure will provide the final connection between the western Lake Washington shoreline in the vicinity of 24th Ave E and the eastbound half of the new floating bridge.

PERMIT/ESA CONDITIONS

Incidental take of Puget Sound Chinook, Puget Sound steelhead, and Coastal-Puget Sound bull trout in the form of harm or harassment as a direct effect of exposure to elevated underwater SPLs may result from the use of impact hammers. Impact hammers shall only be used when site conditions are encountered that prevent effective use of vibratory hammers and for determining load-bearing capacity (proofing). The extent of the effects to fish life due to impact pile driving authorized under the Endangered Species Act are based on the following maximum impact assumptions:

Table 1
Maximum Impact Limits

	Work Access Location	
	Union Bay **West of Foster Island**	**West Approach** **East of Foster Island**
Timing	Sept. 1 – April 30	Oct. 9 – April 14
Maximum Piles per Day	16	12
Maximum Strikes per Pile	500	500
Maximum Strikes per Day	8,000	6,000
Single Strike Peak Sound Level dB_{PEAK}	188	188

Contractor will implement a bubble curtain noise attenuation device. The bubble curtain will meet all design and performance criteria outlined in the project specifications and will be tested according to Section 2.8.5.3.1 of the technical requirements before driving of any piles.

Hydroacoustic noise levels will be monitored during pile driving activities. Routine monitoring shall be implemented during at least 20 piles west of Foster Island and 20 piles east of Foster Island. For each area, the monitored piles will include the first 10 piles, 5 piles installed at the approximate midpoint, and 5 piles installed near completion of impact pile driving operations for each in-water work window.

If the SPL threshold of 188 dB measured at 10 meters is exceeded during driving of any of the 10 initial piles, driving activities will cease until the contingency measures noted in this Plan have been instituted. WSDOT will be notified within 24 hours of any exceedance. After installation of the 10th pile, the Engineer of Record (EOR) will review the SPL data and provide approval for continuation of pile driving activities.

The average pile strike count for the first 10 impact driven piles will be used as a Baseline Pile Strike Count for ensuing impact pile driving during the same in-water work window.

If any of the following circumstances arise, the contractor will cease driving activities and institute contingency measures:

1) The threshold SPL is exceeded during initial hydroacoustic monitoring (first 10 piles),
2) The Baseline Pile Strike Count is exceeded by 50 percent for four consecutive piles during subsequent instances of hydroacoustic monitoring,
3) The maximum approved pile strikes per day is reached (refer to Table 1 above).

Contingency measures will include, but not be limited to, the following:

1) Troubleshoot bubble curtain:
    a. Adjust air system delivery,
    b. Adjust compressor output,
    c. Adjust flow regulating valves,
    d. Add additional bubble ring if water depth allows.
2) Pile caps

If circumstance #2 above occurs, contingency hydroacoustic monitoring will be performed during impact driving of the next 5 piles after instituting contingency measures. Contingency monitoring as detailed in the methodology section will document the effectiveness of the noise attenuation device and resulting peak sound levels.

The contractor will cease pile driving for a minimum overnight break period of nine hours between successive days of pile driving.

PILE INSTALLATION LOCATION

Figures 2 through 8 indicate the location of the proposed piles that will be monitored. There will be a total of 776 piles driven as part of the Montlake Phase.

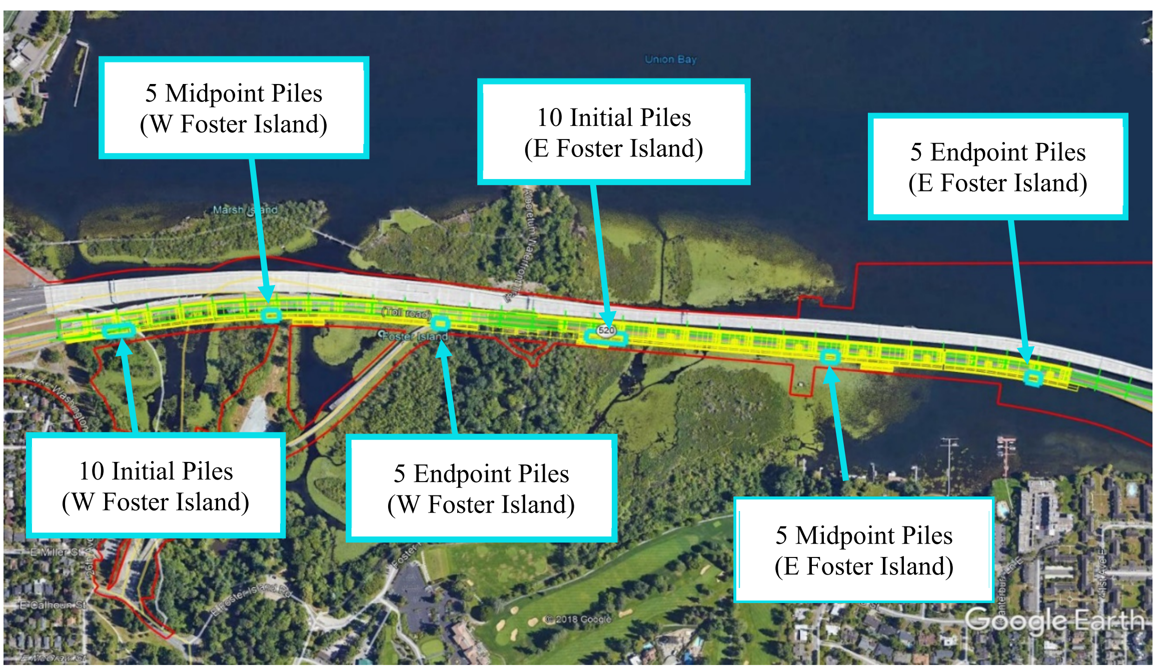

Figure 2. Overview of where pile driving monitoring will take place.

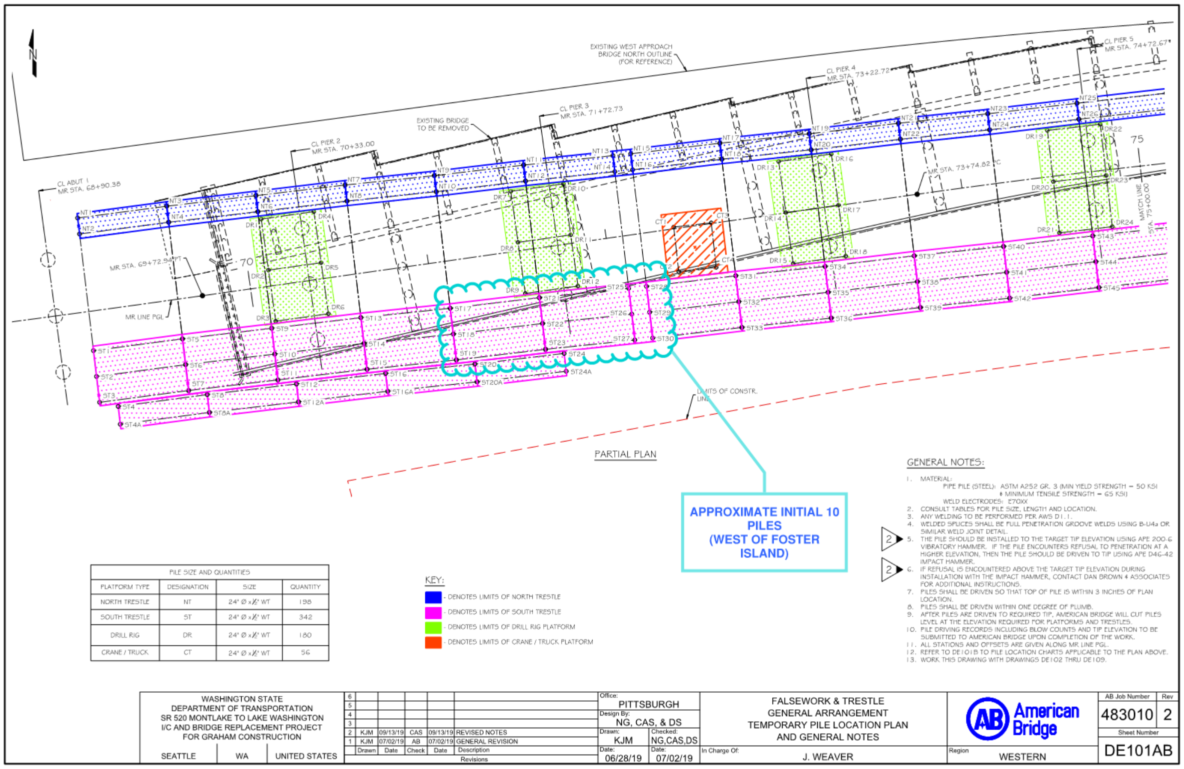

Figure 3. Detail of 10 Initial Piles West of Foster Island

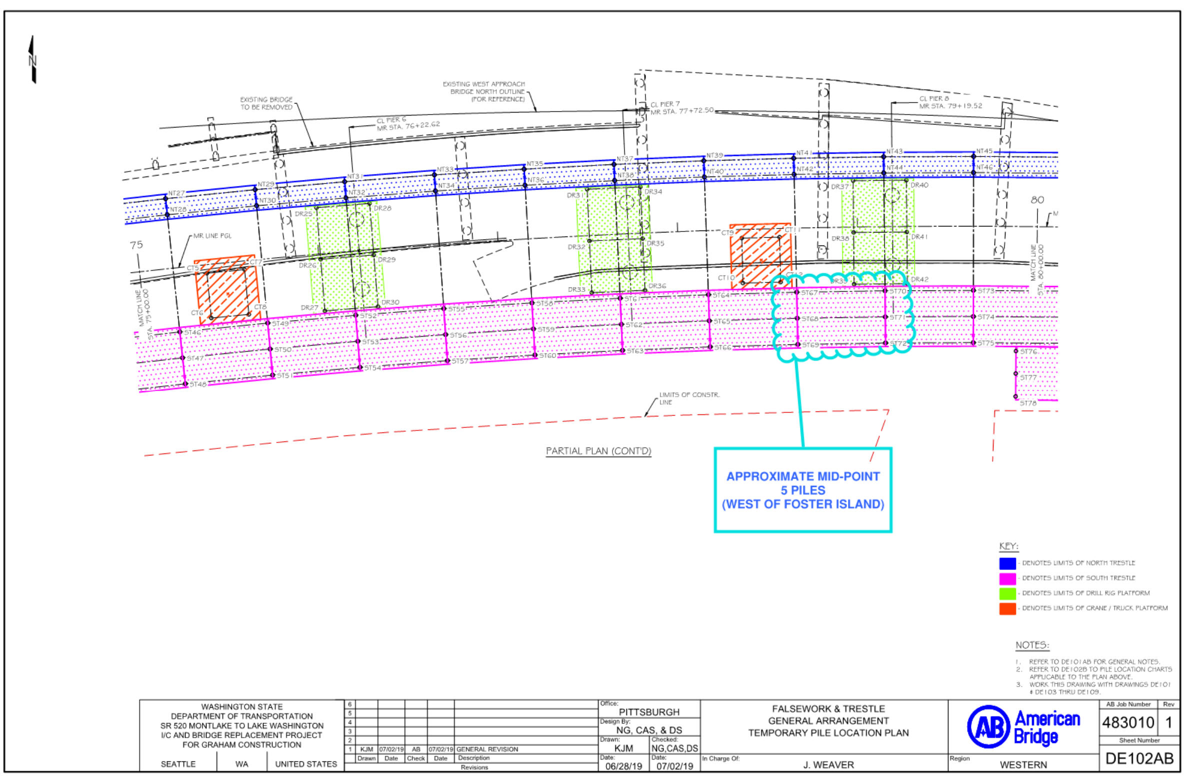

Figure 4. Detail of 5 Midpoint Piles West of Foster Island

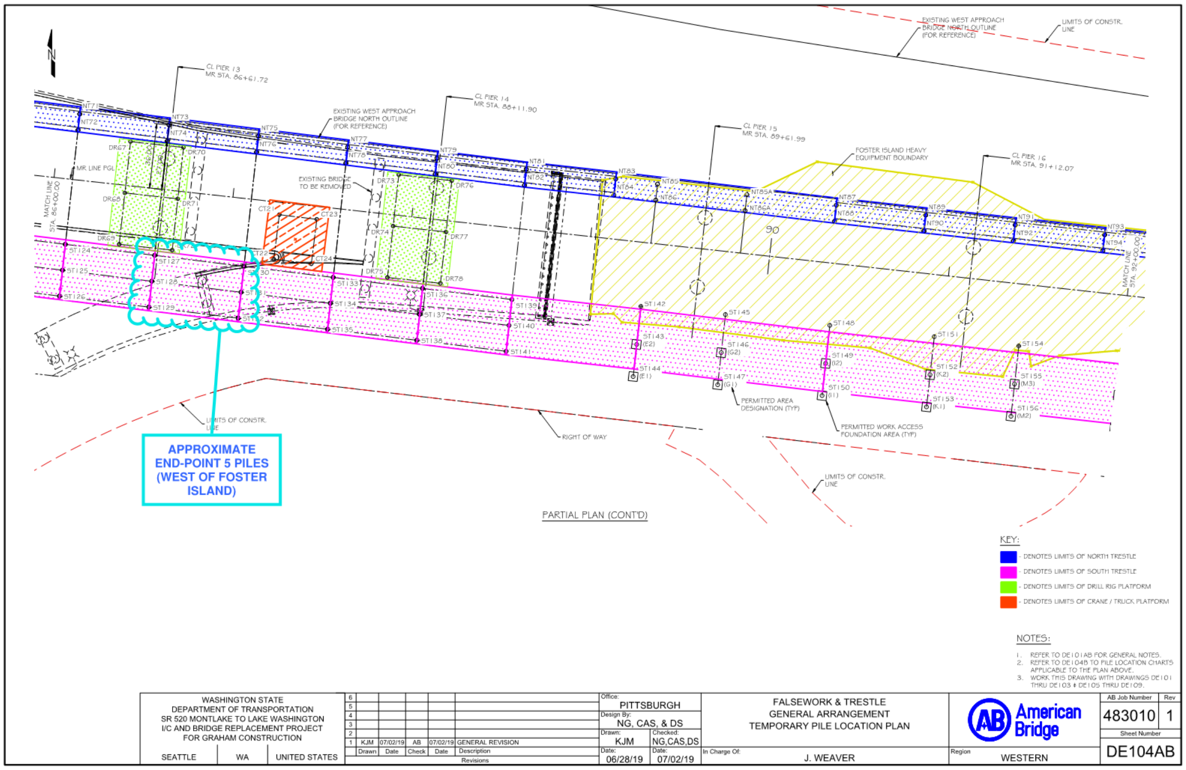

Figure 5. Detail of 5 Endpoint Piles West of Foster Island

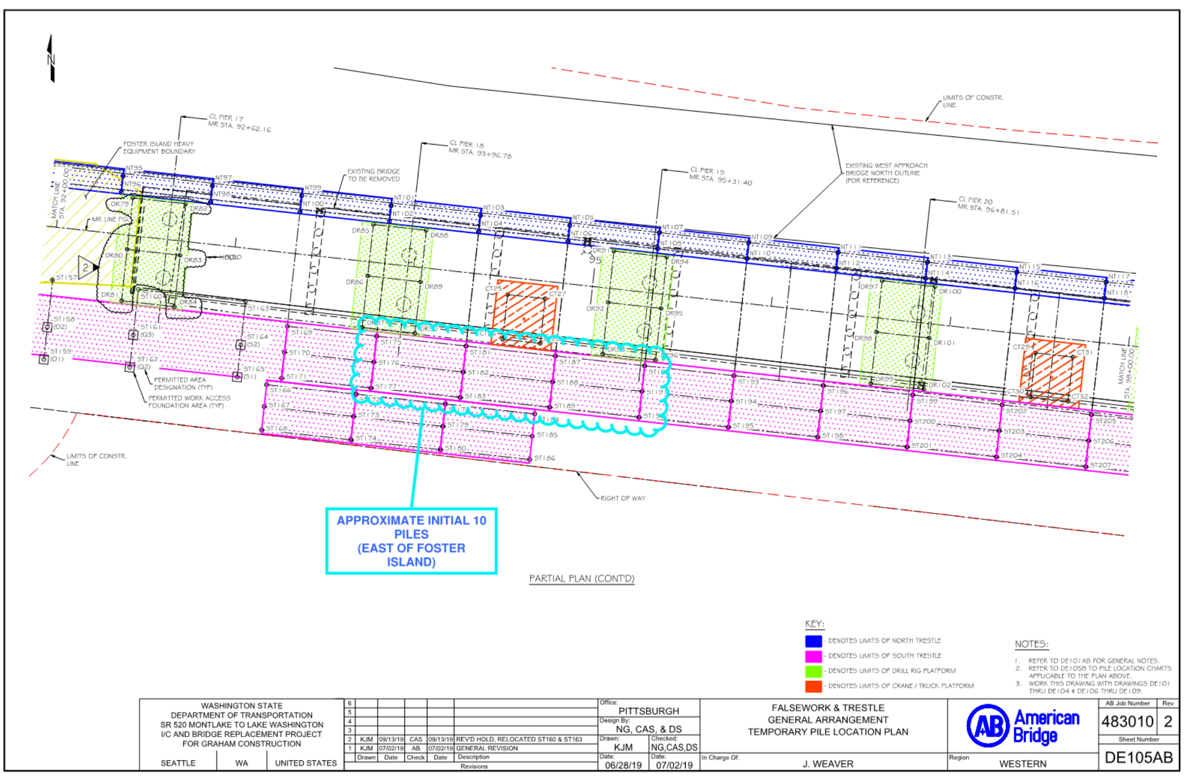

Figure 6. Detail of 10 Initial Piles East of Foster Island

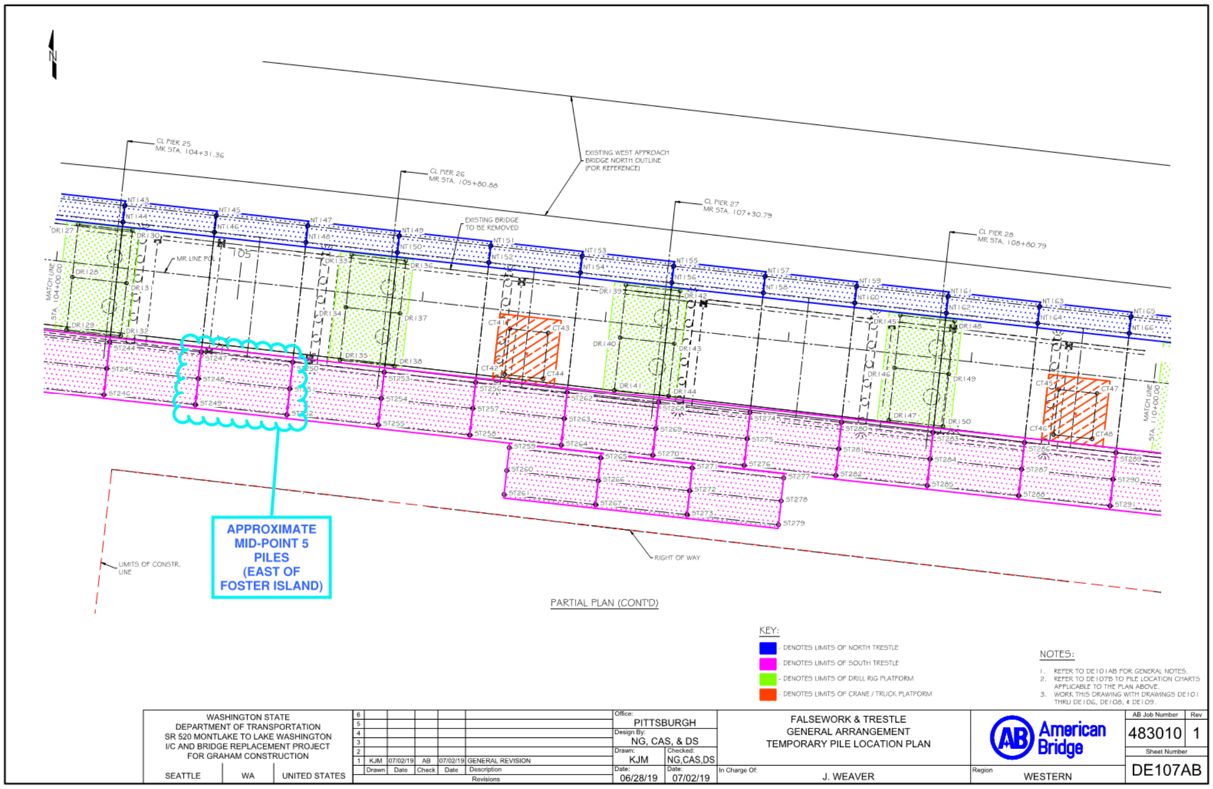

Figure 7. Detail of 5 Midpoint Piles East of Foster Island

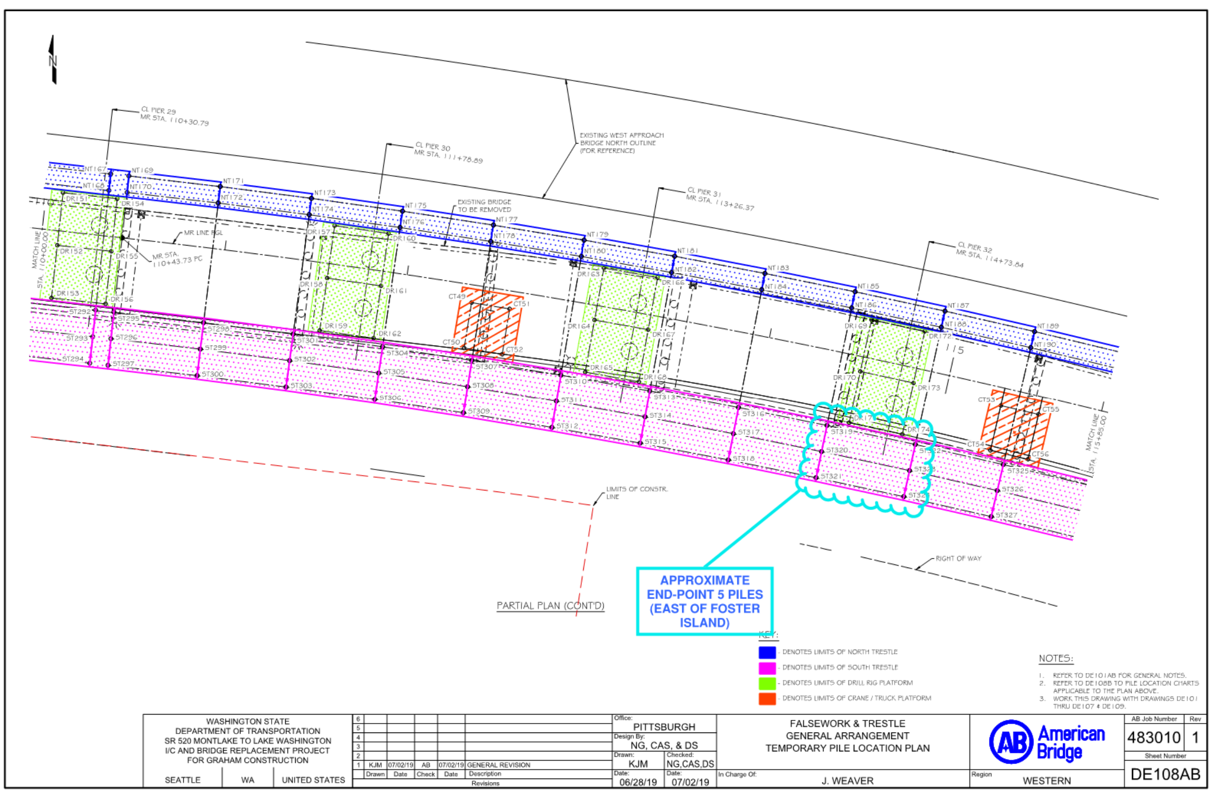

Figure 8. Detail of 5 Endpoint Piles East of Foster Island

PILE INSTALLATION

Hydroacoustic monitoring will be conducted for 40 piles struck with an impact hammer. An APE Model D46 single acting impact hammer will be utilized. The hammer is diesel run with a 4,600 kg (10,120 lb) piston and has four energy settings ranging from approximately 55,000 ft-lbs to 114,000 ft-lbs. Piles chosen to be monitored are driven in water depths that are representative of mid-channel or typical water depths at the project location where piles will be driven. Bathymetry, total number of piles to be driven, depth of water, and distance from shore were also taken into consideration when choosing representative piles.

Hydroacoustic monitoring of 24-inch hollow steel pile driving will include:

- Monitoring a minimum of 40 piles, out of a total 776 piles.
- Testing of sound attenuation system effectiveness.

Hydrophones will have a clear acoustic line-of-sight between the pile and the hydrophone. Table 1 lists the water depth, and the number and size of piles that will be monitored during installation in association with the southern bridge trestle.

Table 1
Depth, Number Piles to be Monitored

Structure	Water Depth	Structural Components Installed
South Trestle	3 feet to 15 feet	40 - 24-inch diameter ½" hollow steel piles

METHODOLOGY

The hydrophone will be placed at the midpoint of the water depth. Measurements will be conducted at the adjacent bridge deck. The hydrophone will be placed at a distance of 10 meters from each pile being monitored.

A weighted tape measure will be used to determine the depth of the water. The hydrophone will be attached to a nylon cord, which will be attached to an anchor that will keep the line the appropriate distance from the pile. The cord will also be attached to a float or tied to a static line at the surface. Distances will be measured with a range-finder, with direct line of sight between the pile and the hydrophone in all cases.

The hydrophone calibration will be checked at the beginning of each day of monitoring activity. NIST traceable calibration forms shall be provided for all relevant monitoring equipment. Prior to the initiation of pile driving, the hydrophone will be placed at the appropriate distance and depth as described above.

The onsite inspector/contractor will inform the acoustics specialist when pile driving is about to start to ensure that the monitoring equipment is operational. Underwater sound levels will be continuously monitored during the entire duration of each pile being driven with a minimum one-third octave band frequency resolution. The wideband instantaneous absolute peak pressure and Sound Exposure Level (SEL) values of each strike, and daily cumulative SEL should be monitored in real time during construction to ensure that the project does not exceed its authorized take level. Peak and rms pressures will be reported in dB (re:1 μPa). SEL will be reported in dB (re: 1 $\mu Pa^2 \cdot sec$). Wideband time series recording will be performed during all impact pile driving.

Environmental data will be gathered during pile driving activity, including an estimation of wind speed and direction, air temperature, weather conditions, water depth, and any other factors that could contribute to the underwater sound levels, such as aircraft or boats. The start and stop time of each pile driving event and the time at which the bubble curtain is turned on and off will also be recorded.

The contractor will provide the following information, in writing, to the contractor conducting the hydroacoustic monitoring for inclusion in the final monitoring report: a description of the substrate composition, approximate depth of significant substrate layers, hammer model and size, pile cap or cushion type, hammer energy settings and any changes to those settings during the piles being monitored, depth pile driven, blows per foot for the piles monitored, and total number of strikes to drive each pile that is monitored.

Table 2 describes the specifications of the equipment to be used.

Table 2.

Equipment for underwater sound monitoring (hydrophone, signal amplifier, and calibrator). All have current National Institute of Standards and Technology (NIST) traceable calibration.

Item	Specifications	Minimum Quantity	Usage
Hydrophone with 10m of cable (Teledyne TC4040)	Receiving Sensitivity -206dB re 1V/µPa	1	Capture underwater sound and convert to voltages that can be recorded/analyzed by other equipment
Signal Conditioning Amplifier (WIA Type 112L)	Amplifier Gain 0.001 V/pC	1	Adjust signals from hydrophone to levels compatible with recording equipment
Calibrator (B&K Type 4229)	Accuracy IEC 942 (1988) Class 1	1	Calibration check of hydrophone in the field.
Portable Dynamic Signal Analyzer (Larson-Davis 831)	Sampling Rate 51.2kHz	1	Analyzes and transfers digital data to laptop hard drive
Digital Audio Recorder (Sony PCM D-50)	Sampling Rate 48 kHz	1	Back-up recording of hydrophone signals
If water velocity ~> 1m/s, Flow shield	Open cell foam cover or functional equivalent	1/hydrophone	Eliminate flow noise contamination
Laptop computer	Compatible with digital signal analyzer	1	Record digital data on hard drive and signal analysis
Real Time and Post-analysis software (Larson-Davis G4 SLM Utility v4.04)	-	1	Monitor real-time signal and post-analysis of sound signals

Monitoring equipment will be set to a minimum frequency range of DC to 20 kHz and a sampling rate of 48 kHz. To facilitate further analysis of data full bandwidth, time-series underwater signal shall be recorded as a wave file (.wav).

Sound Attenuation Monitoring

A bubble curtain that meets the design and performance criteria outlined in specifications used for the SR 520 Test Pile project is required for impact pile driving. Prior to the first use of the bubble curtain during pile driving, the fully assembled system shall be test-operated to demonstrate proper function. The test shall confirm calculated pressures and flow rates.

A minimum of 30 monitored piles will be tested with the sound attenuation system on and off (or presence and absence) to test its effectiveness; a minimum of 5 piles installed during initial driving activity in each area, at the midpoint, and near completion of the piling installation. Testing will involve turning the bubble curtain off, waiting 30 seconds for the peak levels from the un-attenuated pile strikes to stabilize, monitoring the underwater noise levels during unattenuated pile strikes for 30 seconds, then turning the bubble curtain back on. Pile driving will be continuous throughout the tests. To account for varying resistance as the pile is driven, the sound attenuation device will be turned off for periods during the beginning, the middle third, and near the end of the drive.

For piles that require less than five minutes to drive, pile driving will occur for only two periods with the bubbles off; one near the beginning and once near the end of the drive. During any period where the sound attenuation system is turned off (in absence), the total number of unattenuated pile strikes will not exceed 500 per day.

SIGNAL PROCESSING

Post-analysis of the underwater pile driving sounds will include determination of the maximum absolute value of the instantaneous pressure within each strike, the Root Mean Square (RMS) across 90% of the strike's energy value for each absolute peak ($RMS_{90\%}$), number of strikes per pile and per day, number of strikes exceeding 188 dB_{PEAK}, the cumulative SEL (cumulative SEL = single strike $SEL_{90\%}$ + 10*log(# hammer strikes)) and the frequency spectrum both with and without mitigation between 20 and 20,000 Hz for up to eight successive strikes with similar sound levels. Calculation methodology is provided in Appendix A.

ANALYSIS

The single strike SEL associated with the highest absolute peak strike along with the total number of strikes per pile and per day will be used to calculate the cumulative SEL for each pile and each 24-hour period.

In addition, a waveform analysis of the individual absolute peak pile strikes captured during sound attenuation monitoring will be performed to determine any changes to the waveform with the bubble curtain. A comparison of the frequency content with and without noise attenuation will be conducted. Units of underwater sound pressure levels will be dB (re:1 µPa) and units of SEL will be dB (re:1 $\mu Pa^2 \bullet sec$).

REPORTING

Preliminary results for the daily monitoring activities will be reported within 24 hours after monitoring concludes for the day. In addition, a final draft report including data collected and summarized from all monitoring locations will be submitted within 90 days of the completion of hydroacoustic monitoring. The results will be summarized in graphical form and include summary statistics and time histories of impact sound values for each pile. A final report will be prepared and submitted to the Services within 30 days following receipt of comments on the draft report from the Services. The final report shall include:

1. Size and type of piles.
2. A detailed description of the bubble curtain, including design specifications.
3. The impact hammer energy rating used to drive the piles, make and model of the hammer.
4. A description of the sound monitoring equipment.
5. The distance between hydrophone and pile.
6. The depth of the hydrophone and depth of water at hydrophone locations.
7. The distance from the pile to the water's edge.
8. The depth of water in which the pile was driven.
9. The depth into the substrate that the pile was driven.
10. The physical characteristics of the bottom substrate into which the piles were driven.
11. The total number of strikes to drive each pile and for all piles driven during a 24-hour period.
12. The results of the hydroacoustic monitoring, as described under Signal Processing. An example table is provided in Appendix B for reporting the results of the monitoring.
13. The distance at which peak, cSEL, and rms values exceed the respective threshold values.

REFERENCES

Illingworth and Rodkin, Inc. 2001. Noise and Vibration Measurements Associated with the Pile Installation Demonstration Project for the San Francisco-Oakland Bay Bridge East Span, Final Data Report, Task Order 2, Contract No. 43A0063.

NMFS, 2012a. Guidance Document: Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon. Memorandum: NMFS Northwest Fisheries Science Center – Conservation Biology Division and Northwest Regional Office – Protected Resources Division, January 31, 2012.

NMFS, 2012b. Guidance Document: Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals. Memorandum: NMFS Northwest Fisheries Science Center – Conservation Biology Division and Northwest Regional Office – Protected Resources Division, January 31, 2012.

NMFS, 2012c. Guidance Document: Sound Propagation Modeling to Characterize Pile Driving Sounds Relevant to Marine Mammals. Memorandum: NMFS Northwest Fisheries Science Center – Conservation Biology Division and Northwest Regional Office – Protected Resources Division, January 31, 2012.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33(4): 411-521.

U.S. Fish and Wildlife, 2016. Biological Opinion: State Route 520, Interstate-5 to Medina Bridge Replacement and HOV Project.

APPENDIX A

Calculation of Cumulative SEL

An estimation of individual SEL values can be calculated for each pile strike by calculating the 1 second Leq for each individual pile strike. As can be seen in equation 1 below, the SEL is a subset of the Leq function; when the time interval for the Leq is set to one second it is equal to the SEL. The accumulated SEL values produced by calculating 1 second Leq for each pile strike can therefore be accumulated for each pile strike using the following integral (eq. 1).

$$L_{eq,T} = 10\lg\left(\frac{1}{T}\int_0^T \frac{p^2(t)}{p_0^{\,2}}\,dt\right)\ dB \quad = \quad SEL = 10\lg\left(\int_{-\infty}^{\infty} \frac{p^2(t)}{p_0^{\,2}}\,dt\right)\ dB \qquad \text{(eq. 1)}$$

Calculating a cumulative SEL from individual SEL values cannot be accomplished simply by adding each SEL decibel level arithmetically. Because these values are logarithms they must first be converted to antilogs and then accumulated. Note, first, that if the single strike SEL is very close to a constant value (within 1 dB), then cumulative SEL = single strike SEL + 10 times log base 10 of the number of strikes N, i.e, $10Log_{10}(N)$. However if the single strike SEL varies over the sequence of strikes, then a linear sum of the energies for all the different strikes can be computed. This is done as follows: divide each SEL decibel level by 10 and then take the antilog. This will convert the decibels to units of microPascals. Next compute the sum of the linear units and convert this sum back into dB by taking $10Log_{10}$ of the value. This will be the cumulative SEL for all of the pile strikes.

APPENDIX B

Table 1. Example table for required information for reporting the results of hydroacoustic monitoring of pile driving.

Date and Time	Pile ID	Hammer Impact or Vibratory	# Strikes or Vibratory Seconds	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			$SEL_{90\%}$ (dB)				$RMS_{90\%}$ (dB)			Notes
					At Pile	At H-phone	Max	Min	Mean	Max	Min	Mean	$cSEL_{90\%}$	Max	Min	Mean	