
Hydroacoustic Monitoring during Beach Pile Driving at Hood Canal Bridge on June 14th, 2004

Summary Field Report

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June 2004

Prepared for the
Washington State Department of Transportation

Battelle, Pacific Northwest Division
of Battelle Memorial Institute

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INTRODUCTION

As part of the Hood Canal bridge construction support, hydroacoustic monitoring of sound pressure levels from impact driving of steel piles will occur during construction of the temporary work trestle at the eastern bridge approach. While most of this monitoring will occur as piles are driven “in-water” beginning around July 15th, 2004, one day of monitoring was conducted on June 14th, 2004 for impact driving of three steel piles located on the beach, or “in the dry”. The following report is a summary of the field activities and a preliminary analysis of the resulting sound pressure levels and signal characteristics that were recorded.

METHODS

Hydroacoustic monitoring of three “dry” test piles (Pile #'s 710, 721, and 781) occurred on June 14, 2004 at the Hood Canal Bridge on an incoming tide (Figure 1). Two hydrophones were deployed for this monitoring. The first hydrophone, referred to as the “vessel hydrophone”, was tethered off the side of the research vessel, *R/V Strait Science*, at the same stationary location for the duration of the day in approximately 16 feet of water. The vessel hydrophone was located at about mid-water column depth (8 feet). A second hydrophone, referred to as the “float hydrophone” was deployed using a float and anchor system (Figures 2 and 3) tethered to the vessel. The hydrophone float was located in four feet of water with the hydrophone location at mid-water column depth (2 feet). With each successive pile driving event, the float hydrophone was re-located shoreward to maintain the same depth in the water column as the tide came in. The GPS position of both hydrophones was monitored and recorded. Additional data were collected onshore including pile position, distance to the waterline (stand-off distance), and duration and time for each driven pile.. A biologist on board the vessel actively scanned for signs of fish immediately preceding and during each pile driving event. No observations of fish, either alive or dead, were noted during the day.

The impact sound signals were recorded with a dynamic signal analyzer connected to a laptop computer and observed in real-time on the computer screen (Figure 4). The data were also stored on DAT tape using a Sony instrument quality DAT cassette recorder. The DAT tape provides a redundant backup to the data acquired with the signal analyzer. At the initiation of data acquisition a field calibration unit was used to verify that the through system performance of the signal analysis and DAT recording system was correct. Hydrophone calibration signals were acquired by both the signal analyzer and the DAT recording. These signals were later processed to provide scaling factors to convert electrical units to engineering units. Following calibration checks, for each of the three piles data acquisition was initiated with the onset of “dry firing” and terminated at cessation of pile driving activity.

Acquired sound signals were broken into three segments, beginning, middle, and end, for each pile. In each segment a subsample of 27 impact signals were taken for analysis. A number of statistics were extracted from each impact sound included in the subsamples. The peak positive pressure and RMS (root mean square) value for each sampled impact

was determined. RMS values were computed over the impact sound interval containing 95% of the energy in the impact pulse.

Figure 1. Pile driving preparation at Hood Canal Bridge East Approach, June 14, 2004.



Figure 2. Schematic of floating hydrophone platform.

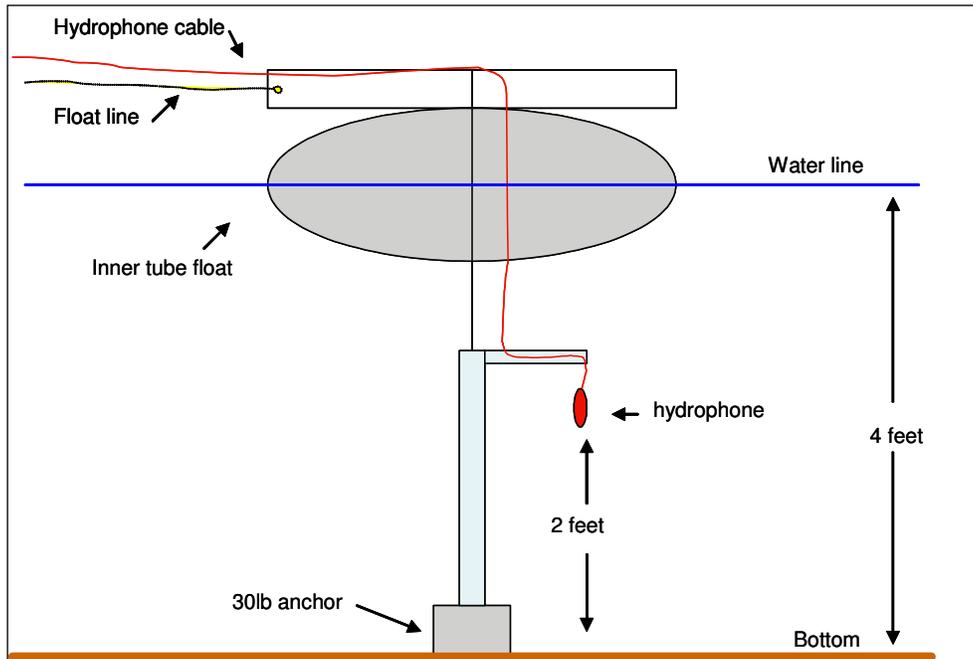


Figure 3. Float hydrophone platform tethered to R/V Strait Science at Hood Canal Bridge test monitoring site.



Figure 4. Equipment used to collect underwater sound pressure data (Hydrophones not shown).



RESULTS

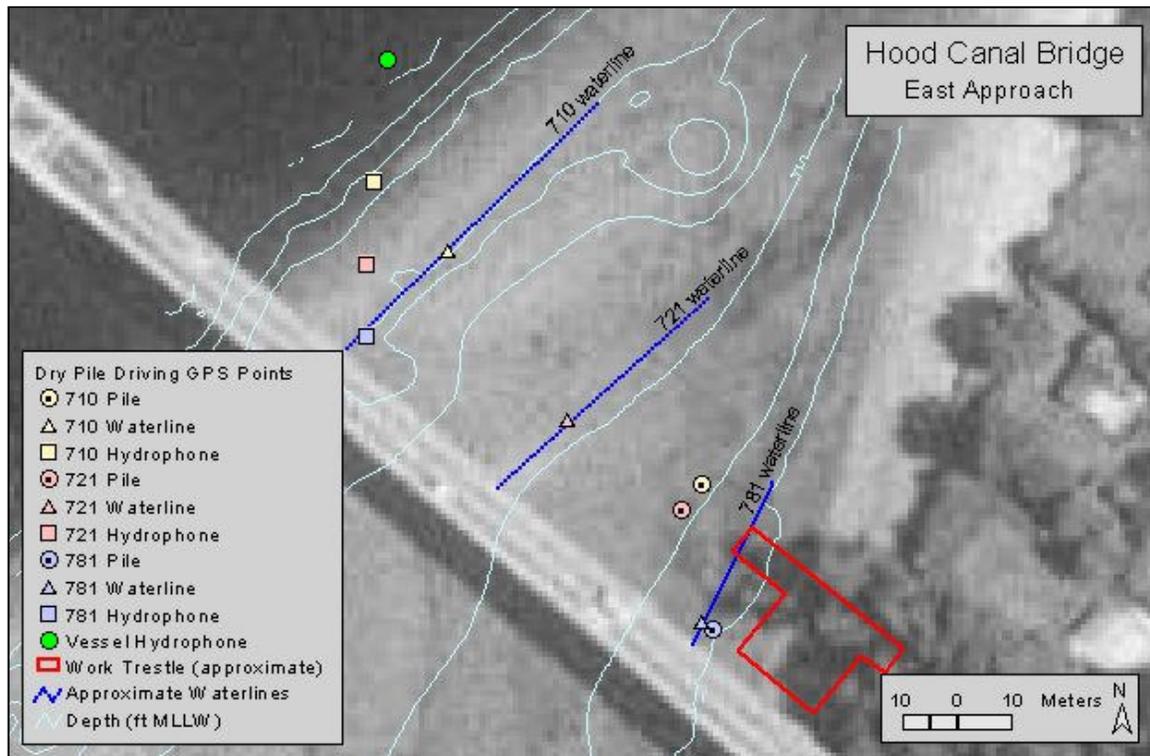
Dry Pile Scenario Characterization

Three 24” diameter steel piles were driven using an open diesel hammer on June 14th, 2004. Table 1 shows the location of each pile and hammer duration, as well as distances between hydrophones and each pile driven. The piles were driven in the “dry” at variable distances to the water line. Figure 5 shows the GPS location of the piles, vessel and float hydrophones, and approximate waterline throughout the course of the day.

Table 1. Description of piles driven at east Hood Canal Bridge construction site on June 14, 2004.

<i>Feature</i>	<i>Pile 1</i>	<i>Pile 2</i>	<i>Pile 3</i>
Pile No.	710	721	781
Position	N47 51.243 W122 36.788	N47 51.222 W122 36.786	N47 51.215 W122 36.786
Start Time ¹	1014 h	1211 h	1308 h
End Time	1028 h	1218 h	1315 h
Duration Full Hammering ²	6.75 min	3.28 min	4.98 min
	<i>Distances (ft)</i>		
Boat to float	67	122	164
Boat to pile	309	317	392
Float to pile	264	237	268
Boat to waterline (dir. of pile)	98	226	384
Float to waterline (dir. of pile)	60	151	262
Pile to waterline (dir. of pile)	204	86	5

Figure 5. Location of vessel, float hydrophones, piles (710, 721, 781), and approximate waterline for each pile driving event.



Signal Characteristics

The waveforms for the sound pressure signals from the pile impacts were similar for all three piles and sampling locations. Using Pile 710 as an example (Figure 6), the sound pressure wave from the impact reaches the float hydrophone first, as expected. The sound pressure is centered around the total pressure present at the hydrophone location. The duration of the segment of the sound impulse containing the most energy in the signal generated by an impact event is 0.025 sec (25 msec). This segment was followed by a longer segment of signal much lower in amplitude lasting about 0.15 sec (150 msec). The impact frequency was about 7 impacts per 10 sec (one impact every 1.4 sec, Figure 7). Background noise levels at the time of the observations, as indicated by signal levels immediately before a pile driving impact event, appeared to be low, less than 50 Pa (<154 dB_{peak}/μPa), however additional analysis of the acquired data would be required to better describe the background noise conditions at the time of the test.

Figure 6. Sound pressure levels (Pascals) for a given impact (Pile 710). Red is float hydrophone and blue is vessel hydrophone.

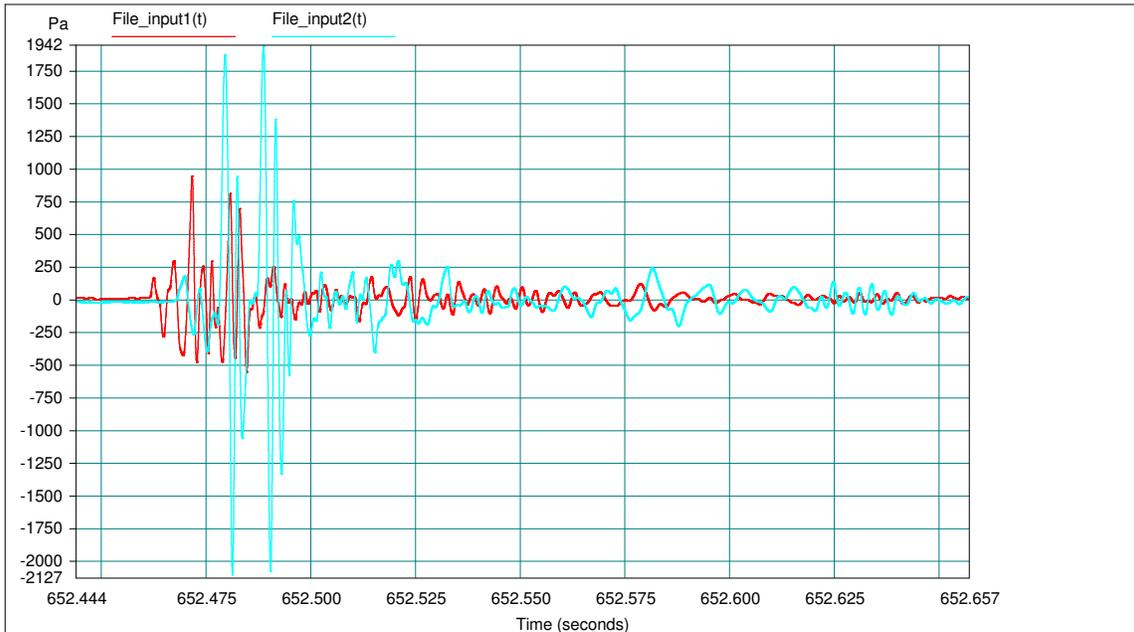
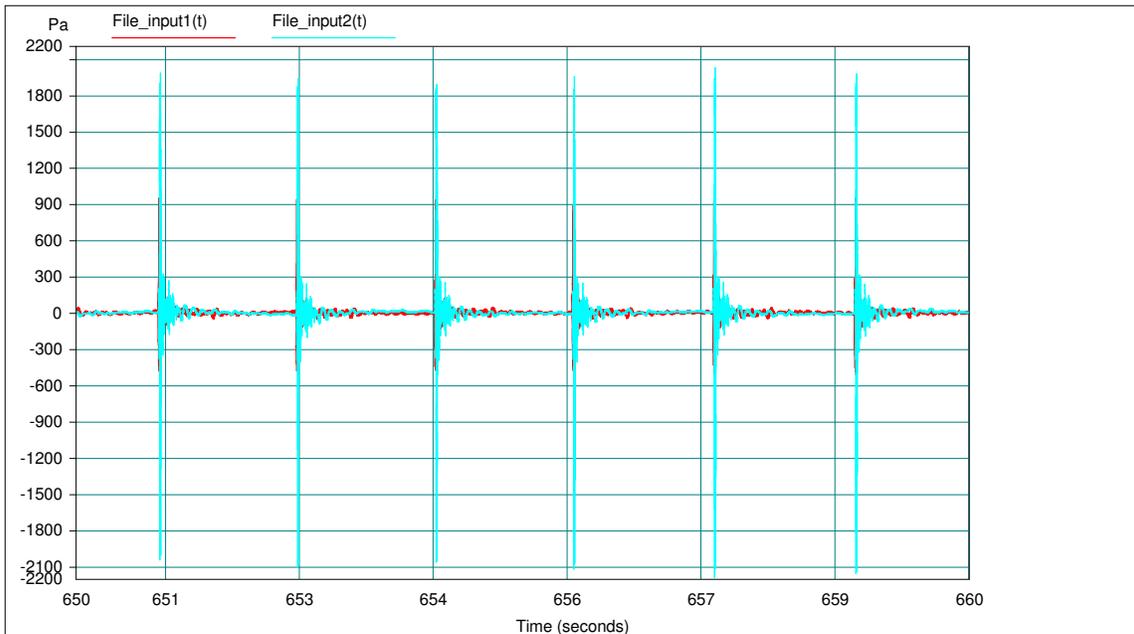


Figure 7. Series of impacts (Pile 710). Red is float hydrophone and blue is vessel hydrophone.

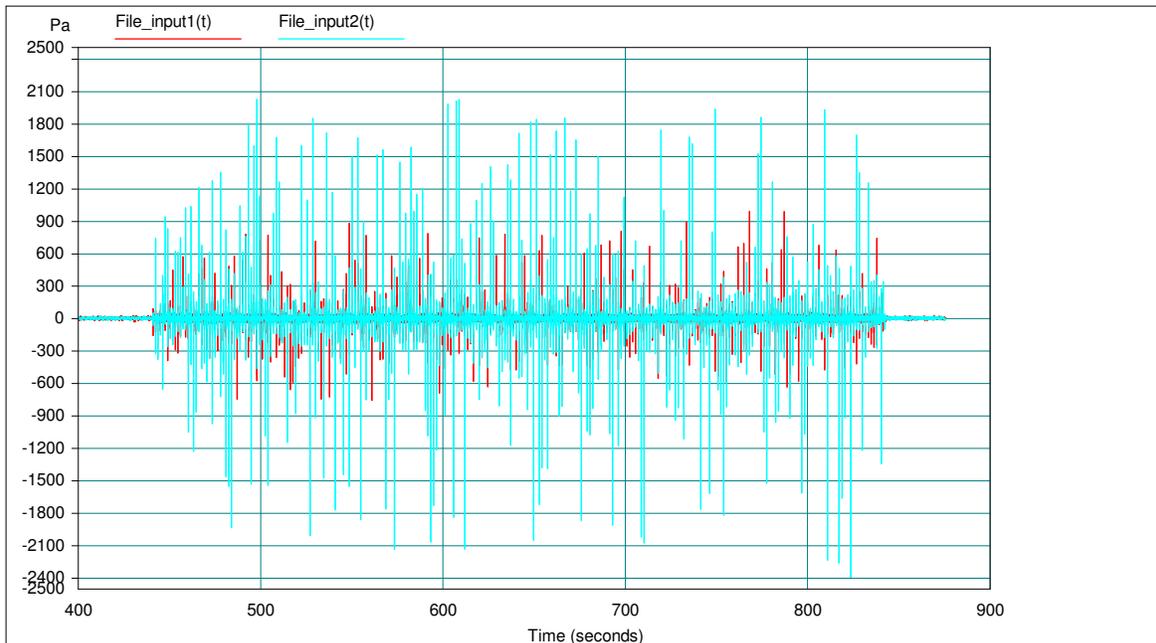


The peak amplitudes of the impact pulses were quite variable over the driving durations (Figure 8). Peak values varied over a range of approximately 6 dB or a factor of 2 in pressure amplitude. Generally, the peak amplitudes of direct path impact signals from a pile driven in water to a monitoring hydrophone located at a range of 10m or so is less variable. Summary statistics for peak and RMS values for samples of individual impact

sound signals were computed for each of the three segments for each test pile. These statistics are presented in Tables 2 and 3.

The sound pressure peak amplitude variability for piles driven in the dry observed during this test likely reflect the complex path for sound from the pile to the monitoring hydrophones.

Figure 8. Pressures (Pascals) for the total event for Pile 710. Red is float hydrophone and blue is vessel hydrophone.



The frequency spectrum (Figure 9) for a few impulses were examined. In general the spectra for the analyzed impact pulses were typical for the sound generated by impact pile driving on smaller diameter steel pile. Most of the sound energy was in the 100-300 Hz range. The energy had diminished greatly by 1200 Hz.

Figure 9. Frequency spectrum (Pile 721). Red is float hydrophone and blue is vessel hydrophone.
Signals by Total Event

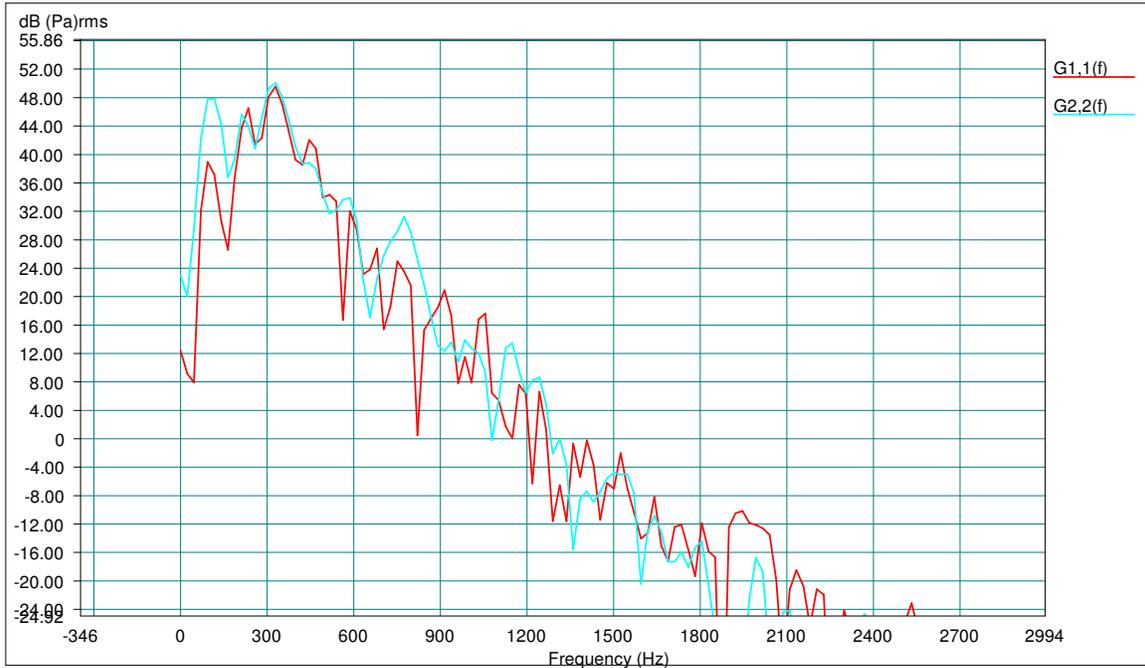


Table 2. Distribution statistics of peak sound pressure levels, root mean square (RMS) sound pressure levels, and frequency content for vessel hydrophone.

Distribution Statistics for Peak Sound Pressure Levels (dB//1 micro Pa) for Hydrophone 187 (Vessel Hydrophone)

File ID	Data Segment	Number of Impacts in Segment	Start Hour	Minimum	5th Percentile	10th Percentile	25th Percentile	Median	Mode	Mean	Standard Deviation	75th Percentile	90th Percentile	95th Percentile	Maximum
710	1	27	9.30	169.0	169.0	169.0	174.6	176.8	169.0	176.8	4.0	180.4	181.9	181.9	182.2
	2	27	9.35	138.8	138.8	138.8	182.7	183.0	138.8	174.2	17.8	183.2	183.3	183.3	183.5
	3	27	9.40	145.9	145.9	145.9	164.1	182.8	145.9	170.4	15.4	183.0	183.1	183.2	183.3
721	1	27	11.19	135.2	144.3	145.2	165.3	168.3	172.0	166.3	12.0	173.3	179.9	180.1	180.5
	2	27	11.22	140.3	180.4	181.0	180.4	180.4	180.4	177.2	12.0	181.5	181.9	181.9	182.1
	3	27	11.24	166.7	172.9	177.1	180.5	180.7	180.8	179.8	2.8	180.8	181.1	181.1	181.2
781	1	27	12.12	159.2	162.1	162.2	164.0	170.3	164.4	168.4	4.2	172.0	172.4	172.5	172.6
	2	27	12.17	144.1	172.5	172.5	172.8	173.2	172.8	171.8	6.3	173.6	173.7	173.8	173.8
	3	27	12.18	144.0	144.0	173.6	173.6	173.7	173.6	171.9	7.1	173.9	174.0	174.0	174.2

Distribution Statistics for RMS Sound Pressure Levels (dB//1 micro Pa) for Hydrophone 187 (Vessel Hydrophone)

File ID	Data Segment	Number of Impacts in Segment	Start Hour	Minimum	5th Percentile	10th Percentile	25th Percentile	Median	Mode	Mean	Standard Deviation	75th Percentile	90th Percentile	95th Percentile	Maximum
710	1	27	9.30	154.3	154.3	154.3	160.7	167.2	154.3	166.2	6.6	172.0	174.0	174.5	174.9
	2	27	9.35	136.9	136.9	136.9	173.3	175.1	136.9	167.4	15.4	175.4	176.0	176.1	176.1
	3	27	9.40	141.5	141.5	141.5	148.0	172.8	141.5	161.1	14.4	173.9	174.2	174.3	174.4
721	1	27	11.19	137.0	138.9	141.0	146.9	150.3	152.6	152.7	9.1	159.0	168.2	169.3	169.4
	2	27	11.22	135.5	135.5	160.3	160.3	168.4	160.3	163.6	9.8	169.3	169.6	169.9	170.2
	3	27	11.24	155.5	155.5	160.6	160.7	163.1	160.7	162.8	3.2	164.8	167.4	168.4	168.4
781	1	27	12.12	140.9	142.6	144.8	147.2	153.1	147.6	151.3	4.7	155.2	156.2	156.7	157.2
	2	27	12.17	140.4	154.2	154.2	156.3	157.9	154.2	156.8	4.2	159.3	159.9	160.2	160.4
	3	27	12.18	139.3	139.3	156.3	158.7	159.3	156.3	158.3	5.1	160.3	161.0	162.8	165.8

Frequency Content Distribution Statistics for Hydrophone 187 (Vessel Hydrophone)

File ID	Data Segment	Start Hour	25th Percentile	Peak Frequency	Mean Frequency	75th Percentile
710	1	9.30	101.2	157.8	149.5	199.8
	2	9.35	85.4	153.2	136.3	170.9
	3	9.40	69.7	135.1	129.8	165.5
721	1	11.19	56.2	133.6	116.5	163.3
	2	11.22	55.0	118.4	119.3	162.2
	3	11.24	58.4	111.6	116.3	162.0
781	1	12.12	63.0	71.7	88.2	103.8
	2	12.17	71.4	88.2	107.7	157.5
	3	12.18	70.4	84.5	103.1	152.2

Table 3. Distribution statistics of peak sound pressure levels, root mean square (RMS) sound pressure levels, and frequency content for float hydrophone.

Distribution Statistics for Peak Sound Pressure Levels (dB/1 micro Pa) for Hydrophone 186 (Float Hydrophone)

Pile ID	Data Segment	Number of Impacts In Segment	Start Hour	Minimum	5th Percentile	10th Percentile	25th Percentile	Median	Mode	Mean	Standard Deviation	75th Percentile	90th Percentile	95th Percentile	Maximum
710	1	27	9.30	164.2	164.2	168.2	170.6	172.9	164.2	171.9	2.8	173.6	174.2	175.2	175.7
	2	27	9.35	144.8	176.4	176.5	176.5	176.6	176.5	175.4	6.1	176.8	176.9	177.0	177.0
	3	27	9.40	145.1	157.5	167.2	176.3	176.5	176.7	173.5	7.4	176.7	176.9	177.0	177.0
721	1	27	11.19	152.0	160.8	164.2	169.3	172.8	172.5	171.5	5.3	175.0	176.3	177.1	177.8
	2	27	11.22	145.2	145.2	145.2	182.0	182.3	145.2	176.1	13.9	182.5	182.7	182.7	182.8
	3	27	11.24	167.7	167.7	174.1	174.1	182.3	174.1	179.6	4.4	182.5	182.6	182.7	182.7
781	1	27	12.12	142.0	154.3	158.9	162.5	166.1	167.7	164.3	4.8	167.3	167.9	168.3	168.5
	2	27	12.17	140.1	171.7	171.9	172.1	172.5	173.0	171.7	5.0	172.8	173.0	173.0	173.0
	3	27	12.18	150.5	172.5	172.5	172.7	173.0	173.0	172.7	2.7	173.2	173.6	173.6	173.6

Distribution Statistics for RMS Sound Pressure Levels (dB/1 micro Pa) for Hydrophone 186 (Float Hydrophone)

Pile ID	Data Segment	Number of Impacts In Segment	Start Hour	Minimum	5th Percentile	10th Percentile	25th Percentile	Median	Mode	Mean	Standard Deviation	75th Percentile	90th Percentile	95th Percentile	Maximum
710	1	27	9.30	147.0	147.0	150.5	154.3	155.5	147.0	154.9	3.3	157.1	158.4	159.1	165.0
	2	27	9.35	140.1	157.5	157.6	158.6	159.1	157.5	158.4	3.8	159.8	160.4	160.7	160.9
	3	27	9.40	138.1	142.3	146.4	146.4	156.9	146.4	154.7	5.3	157.3	157.8	158.2	159.9
721	1	27	11.19	149.5	149.6	149.7	152.0	153.4	152.5	154.5	3.9	156.3	159.2	162.4	167.8
	2	27	11.22	141.0	141.0	141.0	163.8	169.1	141.0	164.0	10.8	171.9	172.4	172.5	172.5
	3	27	11.24	154.8	154.8	154.8	155.0	170.8	154.8	166.2	7.5	172.0	172.3	172.4	172.5
781	1	27	12.12	137.5	144.6	144.8	146.8	148.0	147.0	147.6	2.3	149.0	149.7	151.1	151.9
	2	27	12.17	135.4	149.5	149.7	150.0	150.9	150.1	150.7	2.8	151.8	153.1	154.4	156.0
	3	27	12.18	147.9	150.2	150.4	150.7	151.6	150.7	151.6	1.2	152.2	153.8	154.0	154.4

Frequency Content Distribution Statistics for Hydrophone 186 (Float Hydrophone)

Pile ID	Data Segment	Start Hour	25th Percentile	Peak Frequency	Mean Frequency	75th Percentile
710	1	9.30	116.7	175.7	182.8	240.5
	2	9.35	103.8	153.7	146.8	176.5
	3	9.40	102.6	133.3	145.4	179.0
721	1	11.19	112.7	154.0	133.9	169.9
	2	11.22	122.6	156.5	156.6	171.7
	3	11.24	120.1	155.3	155.4	173.2
781	1	12.12	504.7	540.9	607.8	812.4
	2	12.17	294.7	648.6	546.7	762.3
	3	12.18	350.0	351.8	359.2	365.3

Two criteria have been set for the protection of fish in the vicinity of impact driving of steel pile. They are $180 \text{ dB}_{\text{peak}}/\mu\text{Pa}$ and $150 \text{ dB}_{\text{rms}}/\mu\text{Pa}$. Corresponding values in Pa are $1 \text{ kPa}_{\text{peak}}$ and $31.6 \text{ Pa}_{\text{rms}}$. For pure sinusoidal signals, the $150 \text{ dB}_{\text{rms}}/\mu\text{Pa}$, criteria, which is $31.6 \text{ Pa}_{\text{rms}}$, would be $44.7 \text{ Pa}_{\text{peak}}$ or $0.0447 \text{ kPa}_{\text{peak}}$.

Note: The figures show pressure magnitudes in Pascals. To convert these to dB_{peak} re: $1 \mu\text{Pa}$, multiply the absolute value by 10^6 , take the \log_{10} , and multiply by 20.

Figures 8, 10, and 11 show all of the sound pressure data (in Pascals) acquired during driving of each test pile. These visual data were observed by WSDOT and resource agency staff in the field on June 14.

Figure 10. Pressures (Pascals) for the total event for Pile 721. Red is float hydrophone and blue is vessel hydrophone.

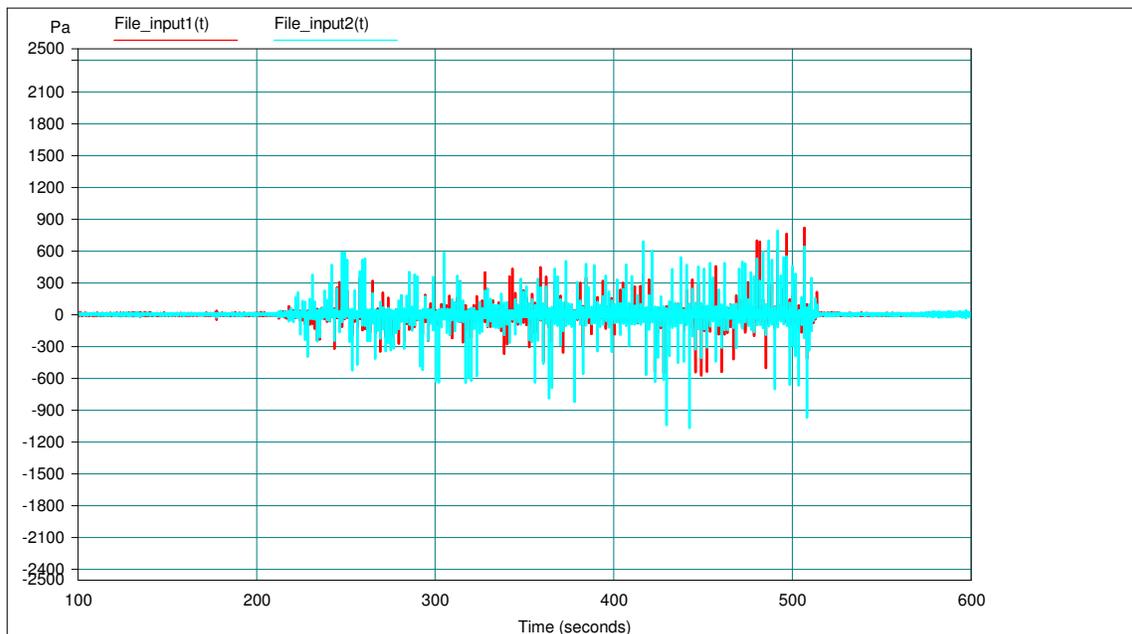
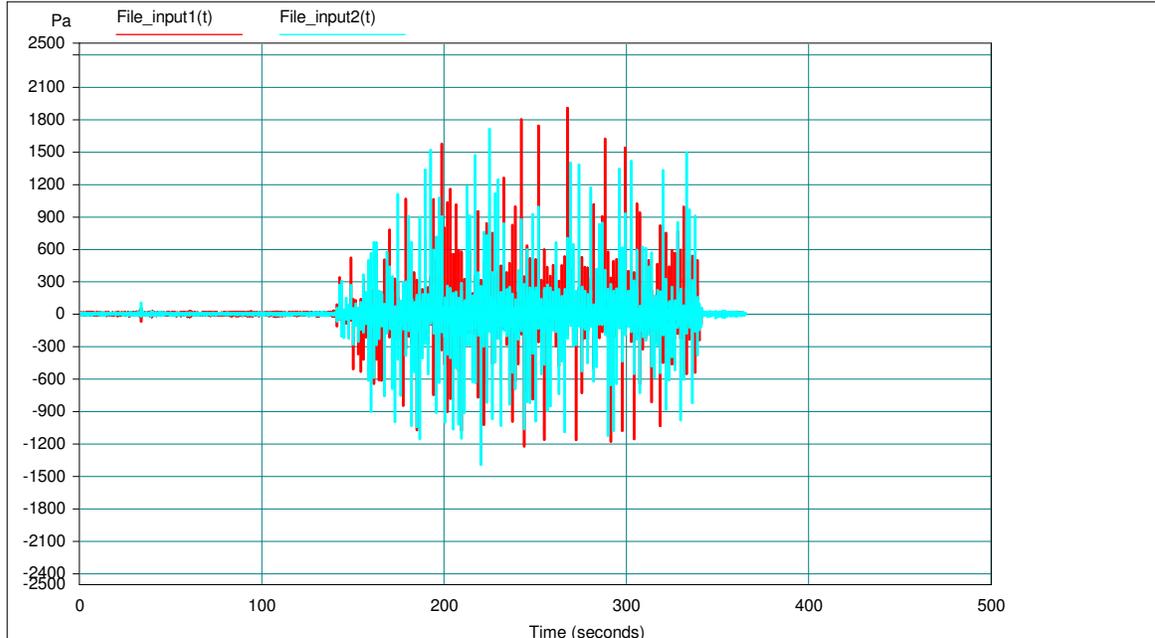


Figure 11. Pressures (Pascals) for the total event for Pile 781. Red is float hydrophone and blue is vessel hydrophone.



The following are observations relative to the 180 dB criterion for each pile.

- Pile 710 – Peak sound pressures were lower at the float than the vessel. Peak sound pressures at the float did not exceed the 180 dB_{peak} (1 kPa_{peak}) criterion whereas those at the vessel did. Exceedance of the criterion at the boat hydrophone was approximately 25%, 75%, and 50% for the subsamples of impacts taken at the beginning, middle, and end of driving (Table 2).
- Pile 721 – Peak sound pressures for both hydrophones showed a high rate of exceedance of the 180 dB_{peak} criterion. Exceedance of criterion at the float hydrophone was approximately 0%, 75% and 50% for the subsampled impacts (Table 3). Exceedance of criterion at the boat hydrophone was higher at approximately 5%, 75% and 75% for the subsampled impact data.
- Pile 781 – All peak sound pressures were below the 180 dB criterion.

The 150 dB_{rms}/μPa criterion was exceeded for all piles at both hydrophones.

- Pile 710 – Approximate exceedance of the criteria was 90%, 90%, and 75% at the float hydrophone and 100%, 75%, and 50% at the boat hydrophone for the subsampled data from the beginning, middle, and end of pile driving respectively.
- Pile 721 – At the float hydrophone approximate exceedance of criterion was 75%, 75%, and 90%, and at the boat hydrophone approximately 50%, 90%, and 100% for subsampled impact underwater sound events from beginning, middle, and end of pile driving, respectively.
- Pile 781 – While there was no exceedance of the 180 dB_{peak} criterion for this pile, exceedance values were, in general, high for the 150 dB_{rms} criterion. Exceedance was approximately 90%, 75%, and 75% at the float hydrophone and 50%, 95%, and 90% at the boat hydrophone for the subsampled data sets (beginning, middle, and end respectively).

Table 4 shows the counts of signals exceeding the 180 dB criterion. The highest exceedance of the 180 dB criterion, approximately 53% of strikes, was observed for pile 710 at the boat hydrophone. The lowest exceedance of the 180 dB criterion, 0%, was observed for pile 781 at the float hydrophone.

Table 4. Number and percent of sound pressures exceeding the criterion of 180 dB_{peak} re: 1 micro Pascal.

<i>Count</i>	<i>Pile 710</i>	<i>Pile 721</i>	<i>Pile 781</i>
Total Impacts (approx.)	284	128	191
Number Over Criterion at Float (%)	3 (1%)	43 (34%)	0 (0%)
Number Over Criterion at Boat (%)	~150 (53%)	42 (33%)	4 (2%)

CONCLUSIONS

The observed pressure time histories and spectra are similar to those reported for other pile driving monitoring. The range in pressure peak amplitudes appears to reflect the complex path for sound from the piles through soil to water. Peak pressures for individual sound impulses were more variable than those observed for other pile driving where the pile was partially or wholly submerged.

Exceedance of the 180 dB_{peak} criterion, which was greater than 33% for piles 710 and 721, appears to be correlated with the distance from the boat to pile for the boat hydrophone. Boat to pile distances were similar for piles 710 and 721, which had similar criteria exceedance values. Pile 781, which had the lowest exceedance for boat hydrophone observations, also had the longest distance between the boat and pile. It is not clear if it was the increased distance from the pile alone that resulted in the lower exceedance or other factors unknown during this test that may have contributed to generally lower peak pressures. Additional analysis which considers information that may be available for factors such as the force applied to the pile and the nature of the substrate into which the pile was driven may help explain the differences in exceedance of the 180 dB criteria observed for the three test piles.

Exceedance data for the 150 dB_{rms} criterion was high overall with no clear pattern related to the relative location of the pile from the hydrophones. It is not clear if these results are due to unique features of the site or other factors. It is worth noting that this criterion is very low in terms of sound pressure. The criterion is equal to a sound pressure of 31.6 Pa_{rms} which would be the rms value for a sinusoidal signal with a peak amplitude of 44.7 Pa.

These data were collected from piles driven “in the dry”. Additional “in-water” data will be collected in July 2004 (with and without bubble curtain containment) at the Hood Canal Bridge site. In the future, this type of information coupled with specific research to understand sound impacts on fish and diving birds may be used to modify presently existing sound threshold criteria if appropriate.