Washington State
Department of Transportation

Memorandum

May 4, 2010

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SUBJECT: Vashon Ferry Terminal Test Pile Project – Vibratory Pile Monitoring Technical Memorandum.

Underwater Noise Levels

This memo summarizes the vibratory pile driving results measured at the Vashon Ferry Terminal in an effort to collect additional site specific data on underwater and airborne noise levels. Data was collected during vibratory pile driving at the Vashon Ferry Terminal facility on Vashon Island during the month of November 2009.

Four 30-inch diameter steel piles were monitored as they were driven with an APE vibratory hammer. No frequency weighting (*e.g.*, A-weighting or C-weighting) was applied to the underwater acoustic measurements presented in this report.

- Underwater sound levels quoted in this report are given in decibels relative to the standard underwater acoustic reference pressure of 1 microPa.
- Airborne noise levels were measured as A-weighted and then converted to C-weighting to approximate an un-weighted sound level. Airborne noise levels use the acoustic reference pressure of 20 microPa.

Continuous sounds occur for extended periods and are associated with the use of a vibratory hammer. Continuous sounds may disturb whales when they exceed a criterion level of 120 dB RMS, according to current NMFS standards. Therefore, the 120 dB RMS criterion has been adopted in the present analysis.

Near Field Measurements

- Near field measurement were taken within 11 to 16 meters of the pile.
- Table 1 summarizes the results of the near field measurement locations for each pile monitored (Figure 1).
- No noise mitigation was utilized as part of these vibratory measurements.
- Broadband Root Mean Square (RMS) noise levels are reported in terms of the 30-second average continuous sound level and have been computed from the Fourier transform of pressure waveforms in 30-second time intervals.
- Average RMS values ranged from 160 to 169 dB RMS at the near field location with an overall average RMS value of 164 dB RMS. Distances from hydrophone to pile ranged between 11 and 16 meters.

Figure 1: Location of near field monitoring location at the Vashon Ferry Terminal.

Table 1: Summary Table of Underwater Monitoring Results at the Near Field Location.

Pile #	Hydrophone Depth	Distance To Pile (meters)	Absolute Peak (dB)	Average RMS Value (dB)
1	20 feet (midwater)	11	180	169
2	20 feet (midwater)	16	190	160
3	18 feet (midwater)	11	175	160
4	18 feet (midwater)	16	187	160
	Overall Average		**187**	**164**

The results of Table 1 shows RMS values around 160 dB RMS in the near field measurement for most piles. Average RMS values are appropriate for continuous sounds generated during vibratory driving.

AMAR Far Field Measurements

In addition to the near shore noise measurements, far field measurements were taken at distances of 790 meters (Deployment Site 1) and 806 meters (Deployment Site 2) using an Autonomous Multi-Channel Acoustic Recorder (AMAR mini) from Jasco Reasearch Ltd. in Canada. The AMAR was used to determine the accuracy of the estimated range of impacts to marine mammals according to the NMFS underwater threshold of 120 dB RMS. WSF is concerned that the practical spreading model used by NMFS is overly conservative and hopes to use information collected with the AMAR to suggest a more appropriate model (e.g. spherical or cylindrical). WSF hopes measuring underwater noise with the AMAR will allow for fine-tuning of the threshold boundary during future projects.

For this project, the AMAR was deployed at different distances to monitor the vibratory pile driving effort: 790 meters (2,592 feet) for piles 1 and 2 and 806 meters (2645 feet) for piles 3 and 4 (Figure 1).

This device is used to determine if the original estimated range of impacts to marine mammals was accurate or if it was too conservative. It is hoped that information collected using the AMAR mini will enable WSF to suggest a more appropriate model (e.g. spherical or cylindrical) to use that is still conservative but not as conservative as the practical spreading model. It is hoped that for some WSF projects that the AMAR will allow a fine tuning of the threshold boundary during the project.

Figure 2: Locations of AMAR deployment relative to the nearfield monitoring location at Vashon Ferry Terminal.

Table 2: Summary table of underwater AMAR monitoring results at the far field locations.

Pile #	Hydrophone Depth[1]	Distance To Pile (meters)	Absolute Peak (dB)	Average RMS Value (dB)	Transmission Loss[2]
1	30 feet	790	168	126	43
2	30 feet	790	159	130	30
3	97 feet	806	162	127	33
4	97 feet	806	155	131	29
Overall Average			**164**	**129**	**34**

[1] – Depth represents depth as measured from the surface. In all locations the hydrophone was deployed approximately 13 feet above the bottom.

[2] - Transmission loss is a complicated function of local bathymetry, sound-speed profile, range, source frequency, absorption, and scattering (Medwin and Clay, 1998). However, if it is possible to measure both the source and received sound pressure levels, the equation below may be used to calculate the transmission loss (Carr et al., 2006).

$TL_{dB} = SL_{dB} - RL_{dB}$; where SL_{dB} is the measured source level and RL_{dB} is the measured received level

While NMFS uses the practical spreading model to determine the threshold boundary distance, WSF is proposing the use of the spherical model. An example comparison of the two models is described below.

- Practical Spreading Model: Assessing the 120 RMS threshold from the Pile 1 location at 11 meters and measuring 169 dB RMS, the NMFS marine mammal calculator results in a threshold boundary 12.6 miles from the pile.
- Spherical Model: Using the most conservative average RMS value of 131 dB RMS measured 806 meters from Pile 4 and inputting it into the NMFS calculator for marine mammal thresholds, the sound levels should reach the 120 dB RMS threshold at approximately 1.8 miles (i.e., the 120 RMS threshold is reached 2,860 meters from the AMAR which is 806 meters from the pile).

Based on our measurements, the practical spreading model appears overly conservative since it predicts that the measured sound level would occur over 10 miles further out (12.6 miles for the practical spreading model minus 1.8 miles for the spherical model). Comparing the measured AMAR results at 0.5 miles (806 meters) using all three spreading models (practical, spherical and cylindrical) it appears, that on average, the spherical model is more accurate at modeling the actual distance of the measured RMS level for each pile (within an average distance of 528 feet or 0.1 miles). The practical spreading model appears overly conservative by calculating a threshold distance 1.5 miles (7,920 feet) greater than actually measured (Table 3).

Table 3: Comparison of different spreading models using actual measured data.

Spreading Model	Distance From Pile (meters)	Pile #	Transmission Loss[1]	Meters To Measured dB RMS	Miles To Measured dB RMS	Measured Distance at 131 dB RMS (miles)
Practical	11	1	43	8092	5.0	0.5
		2	30	1100	0.7	0.5
		3	33	1743	1.1	0.5
		4	29	943	0.6	0.5
				Average	**1.9**	
		1	43	1554	1.0	0.5
Spherical	11	2	30	348	0.2	0.5
		3	33	491	0.3	0.5
		4	29	310	0.2	0.5
				Average	**0.4**	
		1	43	219479	136	0.5
Cylindrical	11	2	30	11000	6.8	0.5
		3	33	21948	13.6	0.5
		4	29	8738	5.4	0.5
				Average	**40.4**	

[1] - $TL_{dB} = SL_{dB} - RL_{dB}$; where SL_{dB} is the measured source level and RL_{dB} is the measured received level

Preliminary measurements of background levels indicate that the average background RMS level is 124 dB RMS. Therefore, assuming that the vibratory driving noise levels will attenuate to background levels before they reach the 120 dB RMS threshold the distance to reach 124 dB RMS is calculated to be 6.8 miles using the practical spreading model or 1.2 miles using the spherical spreading model. Calculating the threshold to background levels from the AMAR location it would be 1.9 miles using the practical spreading model or 1.6 miles using the spherical spreading model.

There is additional support for the use of the Spherical Model. Carr et al., (2006) found that at the Cacouna LNG terminal in Haro Straight, British Columbia, the sound levels from a vibratory hammer drop below 120 dB for ranges greater than 1.6 km (1.0 miles). These results are consistent with the measured data we collected for the Vashon Ferry Terminal.

However, care should be taken to consider differences in the acoustic environment when extrapolating propagation loss estimates from the Vashon Ferry terminal site to other locations. The water depth at the pile driving site was relatively shallow (30-40 feet) and the bathymetry was characterized by a steeply sloping bottom that dropped away rapidly in the offshore direction at a rate of approximately 25 meters depth per 100 meters distance from shore (~14 degrees slope). As with all empirically derived transmission loss laws, the spherical spreading law suggested for the Vashon site should only be extrapolated to similar acoustic propagation environments.

Comparison of Near Field and Far Field Underwater Measurements

Figure 3 through 6 show the relative differences between the near field RMS values, the far field RMS values and the background RMS values for Piles 1 through 4, respectively. As the figures indicate, the near field RMS values are somewhat variable, whereas the far field and ambient measurements are much less variable. The far field measurements were very close to ambient levels and approximately 30 dB lower than the near field measurements.

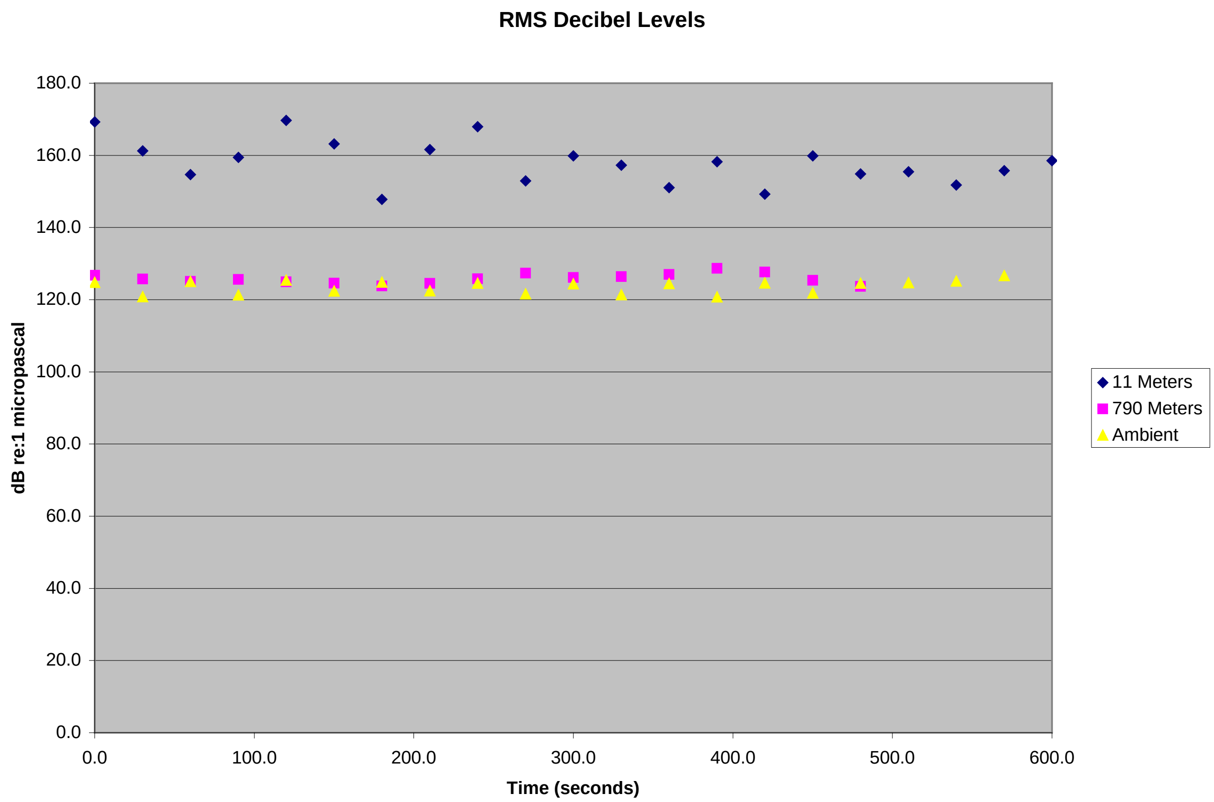

Figure 3: Pile 1 - Comparison of Vibratory Root Mean Square Values (RMS) for 11 meters and 790 Meters from the pile. Ambient RMS values are also included.

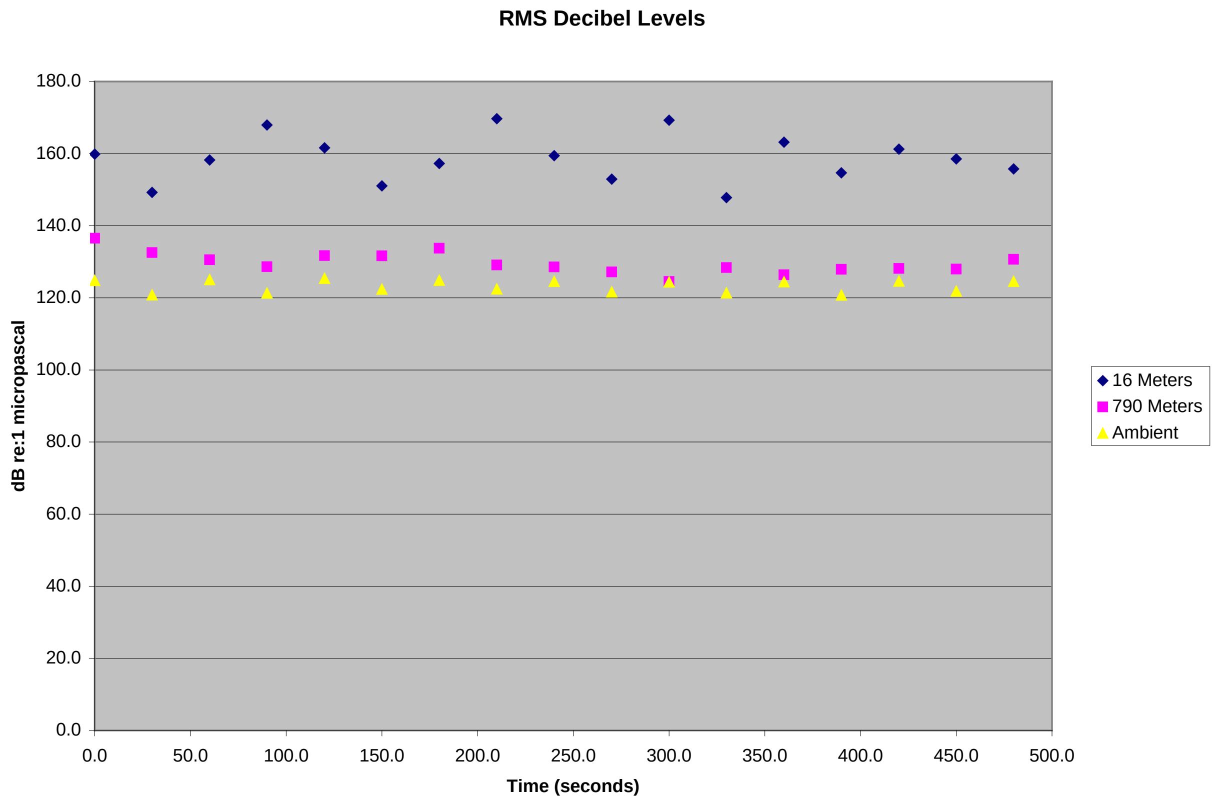

Figure 4: Pile 2 - Comparison of Vibratory Root Mean Square Values (RMS) for 16 meters and 790 Meters from the pile. Ambient RMS values are also included.

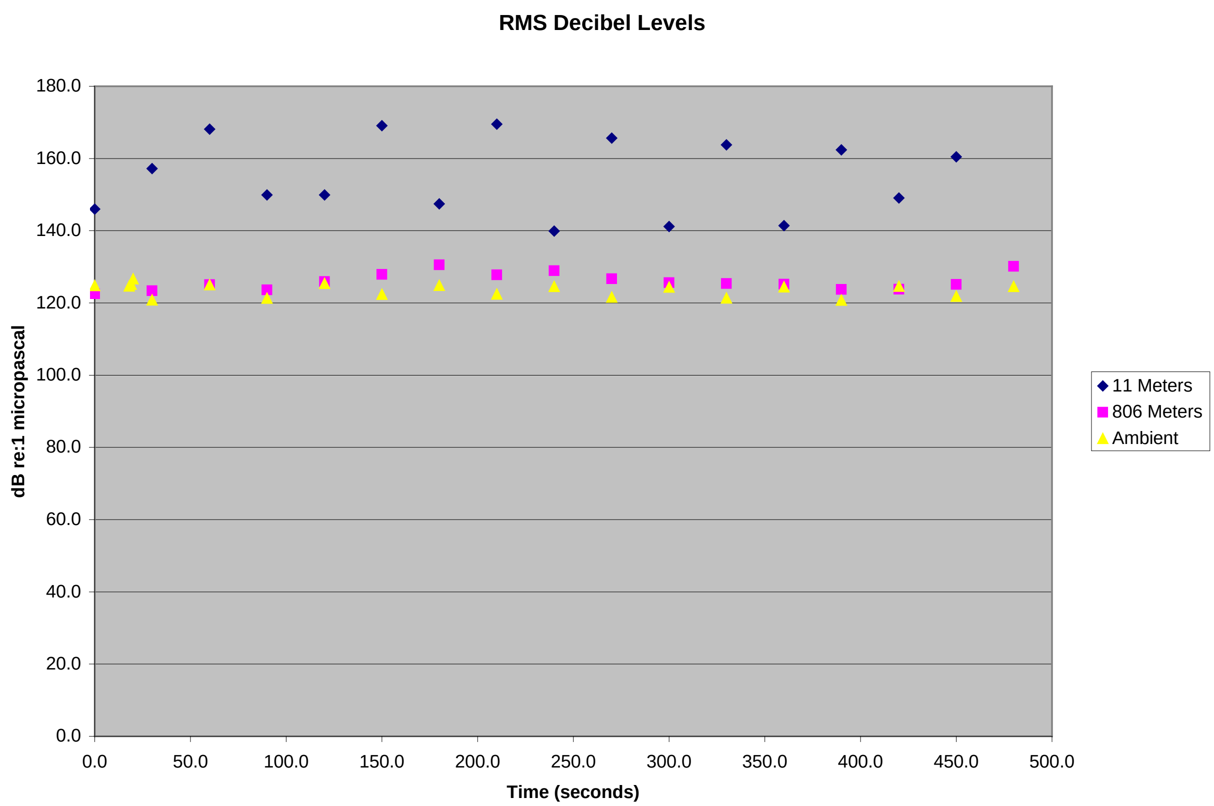

Figure 5: Pile 3 - Comparison of Vibratory Root Mean Square Values (RMS) for 11 meters and 806 Meters from the pile. Ambient RMS values are also included.

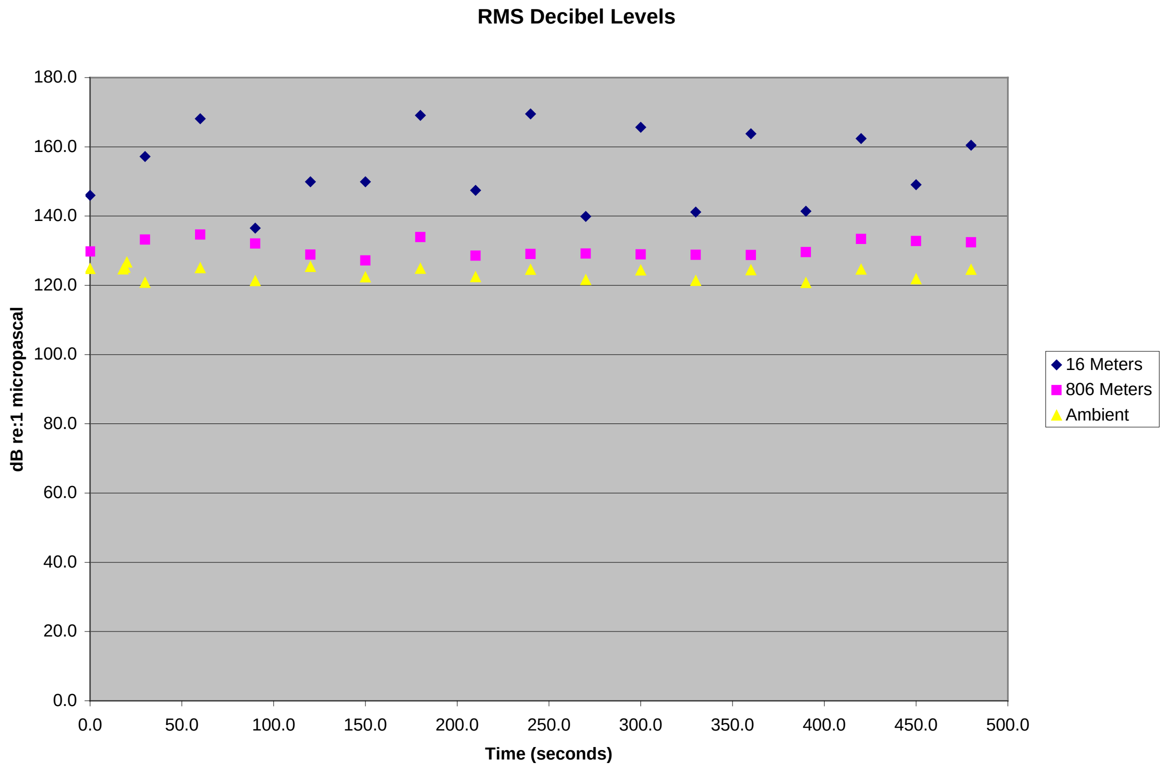

Figure 6: Pile 4 - Comparison of Vibratory Root Mean Square Values (RMS) for 16 meters and 806 Meters from the pile. Ambient RMS values are also included.

Airborne Noise Levels

Airborne noise levels were measured on the four piles at the same time as underwater monitoring of the vibratory driving. Noise levels from these piles are measured in terms of the 15-minute average continuous sound level (15-minute Leq) and described in Table 4:

(15 min) $$L_{eq} = 10\log\left(\frac{1}{T}\int_T p(t)^2\,dt\right)$$

Where p(t) is the acoustic overpressure, T = 15 minutes and 0 < t < T.

RMS values are calculated by integrating the sound pressure averaged over some time period, in this case 15-minutes in a similar way that the Leq values are calculated. Therefore, in this instance the 15-minute Leq is the same as the RMS sound pressure level over a 15-minute period (Table 4).

The 15-minute Leq and Lmax levels were measured with an A-weighting applied. To approximate an un-weighted Leq sound level, a correction factor was applied to the 1/3rd

octave band frequencies and then logarithmically summed to achieve a C-weighted Leq (dBC). The C-weighting approximates an un-weighted sound level (Table 4).

Table 4: Summary Table of Airborne Monitoring Results.

Pile #	Distance from Pile	Leq/RMS (dBA)	Unweighted Leq/RMS (dBC)	Lmax (dBA)
1	26 feet	80.7	84.3	87.8
2	36 feet	81.2	82.7	97.2
3	26 feet	79.8	82.7	84.4
4	36 feet	81.5	85.1	88.9

Figure 7 shows the 1/3rd octave frequency distribution for the A-weighted Leq metric for each pile driven with a vibratory hammer.

- The distributions are all very similar with slight variability in the lower frequencies below 200 Hz.
- The dominant frequency for all piles is around 1.25 kHz and there appears to be a slight increase at 125 Hz for three of the four piles.
- The increase in lower frequencies could be due to longer periods of heavy driving.

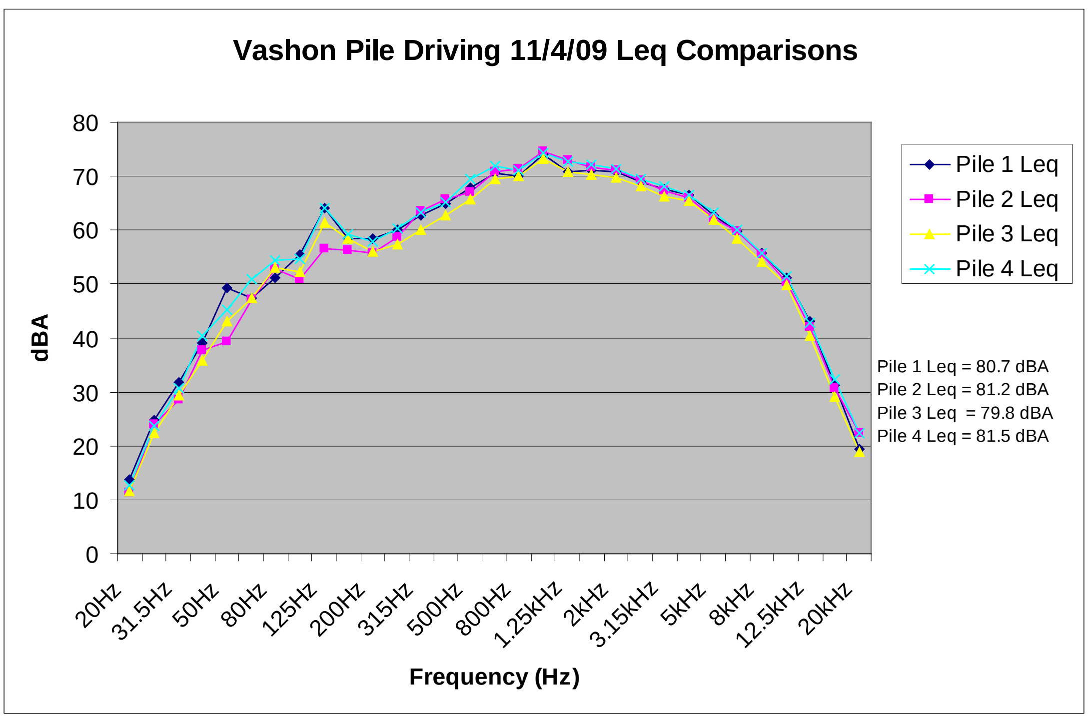

Figure 7: Pile 4 – Comparison of A-weighted frequency distribution for the Leq metric using a vibratory hammer.

Figure 8 shows the 1/3rd octave frequency distribution for the A-weighted Lmax metric for each pile driven with a vibratory hammer.

- The distribution for three of the four piles are similar at frequencies above 1.25 kHz except for Pile 2, which has higher noise levels at the higher frequencies.

- The lower frequencies are more variable, with a similar peak at 125 Hz for three of the four piles.
- The dominant frequency for all piles is between 1.25 kHz and 2 kHz.

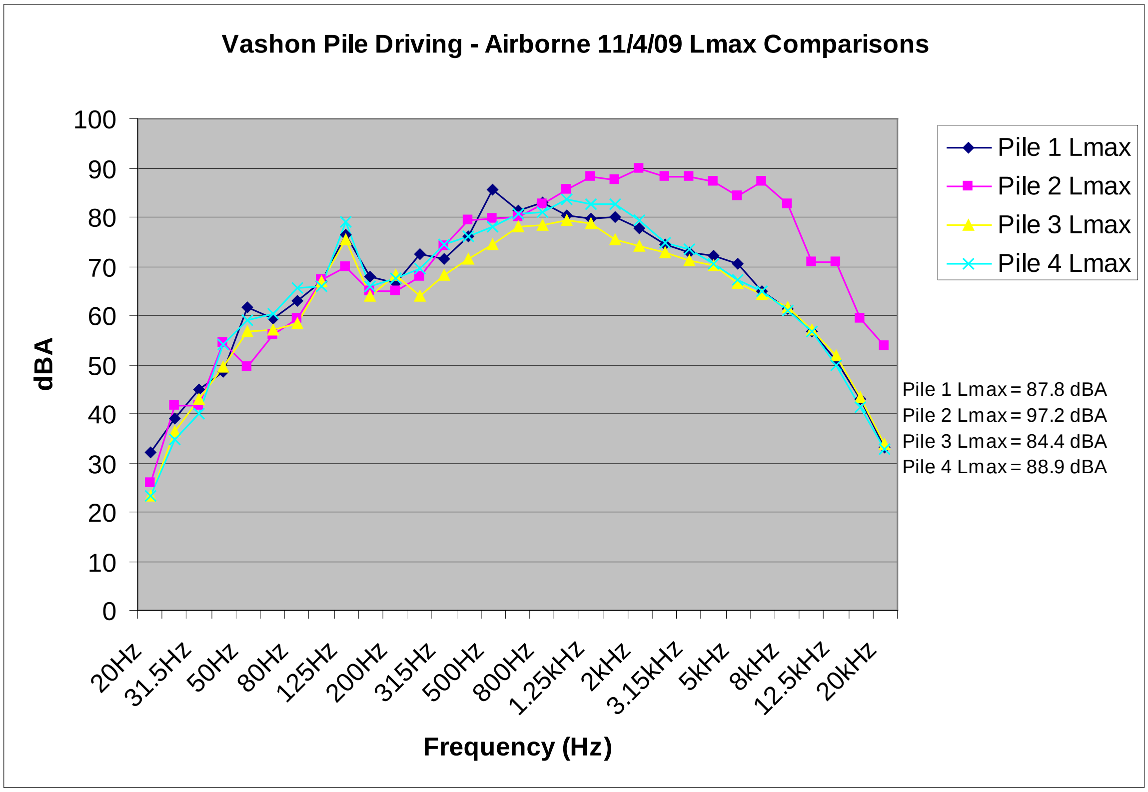

Figure 8: Pile 4 - Comparison of A-weighted frequency distributions for the Lmax metric using a vibratory hammer.

Background Noise Levels

Background noise levels during the daytime are dominated by noise from nearby vessel traffic. Broadband Root Mean Square (RMS) (background) noise levels are reported in terms of the 30-second average continuous sound level and have been computed from the Fourier transform of pressure waveforms in 30-second time intervals. Background levels were measured at 790 meters from the piles using the AMAR system which has a more sensitive hydrophone.

Background RMS values were measured between 122 dB and 125 dB RMS and included some of the contractors equipment running on the barge and local ship traffic. The overall average background RMS value was 124 dB RMS with some minor equipment running.

Conclusions

Near and far field measurements were taken in addition to some background measurements and airborne measurements at the Vashon Ferry terminal during vibratory pile driving. The far field measurements were designed to determine the accuracy of the underwater threshold boundary for marine mammals. RMS values measured at the near field location were lower than previous vibratory measurements made in Puget Sound. The previous measurement reported for Friday Harbor ferry terminal was 177 dB RMS. For the Vashon ferry terminal site the highest RMS value measured in the near field was 169 dB RMS. This difference could be due to improvements in the windowing methods for RMS values since the initial measurement were taken. Using the near field value from the Vashon ferry terminal the practical spreading model estimates the distance to the marine mammal threshold boundary of 120 dB RMS to be over nine miles further out than measurements made at the far field site.

The far field measurements indicate that the RMS values attenuate more quickly than estimated using the practical spreading model. Average transmission loss over the 0.5 mile distance to the far field site was 34 dB. The highest average RMS value measured at the far field site was 131 dB RMS. Using these values the practical spreading model over estimates the actual distance to the measured far field site by 1.4 miles.

Background measurements were taken at the far field location with a more sensitive hydrophone on the AMAR system. Background levels ranged from 122 to 125 dB RMS with an overall average of 124 dB RMS. This value is lower than that reported previously at near shore locations in Puget Sound. However, it was determined that the vibratory sound levels will attenuate to the background levels before reaching the 120 dB RMS marine mammal threshold.

We feel that the practical spreading model is overly conservative and the spherical spreading model is more accurate at the Vashon ferry terminal site. Using the higher RMS values creates a more conservative estimate of the threshold boundary.

The airborne noise measurements may be the first airborne measurements of vibratory driving operations in Puget Sound. The values ranged from 79.8 to 81.5 dB RMS. 1/3rd octave band frequency measurements were collected and corrected to produce a C-weighted Leq value which approximates a flat weighted value. These values ranged between 82.7 and 85.1 dB RMS.

If you have any questions please call me at (206) 440-4643.

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Attachments
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Literature Cited

Carr, Scott A., Marjo H. Laurinolli, Cristina D. S. Tollefsen and Stephen P. Turner. 2006. Cacouna Energy LNG Terminal: Assessment of Underwater Noise Impacts. Jasco Research Ltd., pp. 63.

Medwin, H., and Clay, C. S. (1998) Fundamentals of Acoustical Oceanography. Academic Press, Toronto.